

AN ABSTRACT OF THE DISSERTATION OF

Karlie J. Moore for the degree of Doctor of Philosophy in Exercise and Sport Science presented on December 5, 2012.

Title: Toward the Development of Screening Tests for Heart Attacks and Back Injuries in Firefighters: A Study to Investigate Back-Specific Fitness, Perceived Fitness and Aerobic Capacity in a Firefighter Population.

Abstract approved: _____

Kathy B. Gunter

Firefighting is a very hazardous profession. Firefighters experience an injury rate that is three times higher than other physically demanding professions and the death rate in the fire service is also much higher compared to typical. Throughout the literature, data suggest the physical nature of firefighting contributes to the high incidence of injury and death among firefighters.

As such, special interest groups and firefighting organizations advocate for firefighters to exercise and stay fit in order to safeguard their physical health. Yet, despite these efforts, firefighters still experience a very high incidence of back injuries and heart attacks which can lead to early retirement from disability or death. In the first aim of this dissertation, we examined the relationships between specific back fitness tests and history of back injuries in 113 firefighters in an effort to understand which fitness tests may aid in screening firefighters for risk of back injury. We found that a test of lumbar extension flexibility was associated with a higher incidence of back injuries among our sample ($p < 0.01$). In the second aim of the study, we investigated whether perceived fitness was related to history of back injuries since firefighters' perceptions of their fitness level may direct how they choose to perform job tasks that pose high risk for injury. Within the same sample of firefighters, we found that perceived fitness was not related to history of back injuries nor was the relationship between actual fitness and history of back injuries mediated by perceived fitness. However, perceived fitness correlated with scores on our back strength ($r = 0.28$; $p = 0.003$) and hamstring strength ($r = 0.21$; $p = 0.03$)

tests. In the third aim of the dissertation, we sought to develop a treadmill walking protocol to screen firefighters for low aerobic capacity which is a major risk factor for heart attack. Thirty-eight male firefighters wore a vest weighing 20% of their body weight and performed a walking VO_2max test in which the treadmill grade increased by 1% each minute. The predicted VO_2max from this walking test was very accurate; within a standard error of the estimate of 3.2 ml/kg/min. This new (Moore) protocol requires only a standard treadmill and is more job specific than a running test. In conclusion, more research needs to be conducted to understand how firefighters' perceived fitness directs their behaviors when performing job tasks and how high levels of fitness can protect against back injuries and heart attacks in firefighters. This dissertation has contributed to the development of screening protocols to aid in preventing these adverse events.

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Toward the Development of Screening Tests for Heart Attacks and Back Injuries in Firefighters: A
Study to Investigate Back-Specific Fitness, Perceived Fitness and Aerobic Capacity in a Firefighter
Population

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Karlie J. Moore

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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

Karlie J. Moore, Author

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Toward the Development of Screening Tests for Heart Attacks and Back Injuries in Firefighters: A Study to Investigate Back-Specific Fitness, Perceived Fitness and Aerobic Capacity in a Firefighter Population

CHAPTER ONE

INTRODUCTION

Firefighting is a physically strenuous and dangerous occupation. According to the United States Bureau of Labor Statistics, the combined incidence of injury and illness for firefighters is three times that of workers in the agricultural, construction and manufacturing trades, and almost five times that of miners. Also, firefighters continue to die at a higher than typical rate in the line of duty; there were 72 on-duty firefighter deaths in 2010 and 61 on-duty deaths in 2011 (Fahy R., Leblanc PR, Molis JL).

In their many varied tasks, firefighters must consistently perform intense physical work taxing both the cardiovascular and muscular systems. Throughout the literature, data suggest the physical nature of firefighting contributes to the high incidence of injury and death among firefighters. Three important observations are: 1) the most common cause of injury reported on firefighters' workers compensation claims is overexertion, in which an injury occurred during (or as a result of) a physical effort such as pushing, pulling, lifting or carrying (Karter, Jr. & Molis, 2010; Walton, Conrad, Furner, & Samo, 2003); 2) biomechanical analyses show that the forces placed on the spine when lifting patients and fire hoses are great enough to elicit injury (Gentzler & Stader, 2010; Lavender, Conrad, Reichelt, Johnson, & Meyer, 2000); 3) the risk of experiencing a fatal cardiac event is much greater during or after a firefighter has performed a physically strenuous task, such as fire suppression, compared to a non-emergency task (Kales, Soteriades, Christophi, & Christiani, 2007). As such, special interest groups and firefighting organizations advocate for firefighters to exercise and stay fit in order to safeguard their physical health.

Despite efforts to reduce the incidence of injury and death to firefighters by promoting that they maintain a high level of fitness, these problems remain. Two adverse events, in particular, continue to occur at high rates among firefighters and result in the greatest consequences: back injuries and heart attacks. Back injuries are the most common type of injury experienced by firefighters. They are also the most debilitating and impose the greatest financial burden for fire departments (International Association of Firefighters, 2000; Walton et al., 2003). Heart attacks are the leading cause of on-duty fatalities, contributing to near 50% of firefighter deaths (Soteriades, Smith, Tsismenakis, Baur, & Kales, 2011).

It seems unlikely that these adverse events are still occurring at high rates because all of the firefighters who experience them possess poor fitness. Rather, this may be a reflection that there is a lack of adequate screening protocols to identify firefighters at the greatest risk of injury and heart attack. The lack of available screening tests may be due to the dearth of data relating firefighters' performance on fitness tests to the occurrence of these events. Aside from fitness, there are also psychological factors that may affect injury risk but have not been explored. For example, it is possible that firefighters may choose to take on more physically challenging tasks if they believe themselves to be very fit compared to their peers. Thus it may be interesting to understand the relationships between perceived fitness, actual fitness, risk behaviors and injury in this population to determine whether firefighters who perceive themselves to be highly fit may in fact be at greater risk for injury if they are either a) not fit or b) prone to repeatedly performing the most difficult tasks.

If sufficient screening tests for injury and heart attack are developed, firefighters may have a better understanding of how (and when there is a need) to improve their physical fitness in order to reduce their risk of experiencing these events. Yet, it is also imperative that

screening tests are easy to implement, minimally invasive, and that the equipment and training required to conduct the screenings are accessible for fire departments.

The following pages present a review of the relevant literature about firefighter injury epidemiology, the relationship of fitness and performance to injury among firefighters, a discussion of existing injury screening protocols, and the relationship of firefighters' perceptions of fitness to performance and injury risk. This section also presents the applicable literature regarding heart attack incidence and risk among firefighters, and current approaches to risk assessment and reduction. To conclude, we highlight gaps in the literature and discuss in brief, how the work included in this dissertation may significantly contribute to our current understanding.

BACKGROUND

Injuries in Firefighters

Firefighters experience injuries at a rate three times greater than that of the general work force (United States Bureau of Labor Statistics, 2010). According to the most recent report from the United States Fire Administration, firefighters incurred 81,070 injuries on average each year between 2006 and 2008; about half of these occurred when responding to a fire (United States Fire Administration, 2011). Similarly, in 2009, the National Fire Protection Association estimated that 41.2% of 78,150 total injuries to firefighters resulted from fighting fires (Karter, Jr. & Molis, 2010). Injuries experienced while fighting a fire typically occur due to one of the following six scenarios: overexertion/strain (25%), exposure to hazard (20%), contact with object (16%), slip/trip (12%), fall (10%) and struck/assaulted (7%), while 10% of all injuries fall into the “other” category (United States Fire Administration, 2011).

The prevalence of injuries experienced by firefighters during non-fire emergencies has been increasing steadily over the past 20 years as well (International Association of Firefighters, 2000). Non-fire situations where injuries occur include fitness training, job-specific training, and hazardous material incidents, among others (Poplin, Harris, Pollack, Peate, & Burgess, 2011). The overall number of injuries firefighters experience during non-fire emergency medical calls has escalated over the past two decades largely due to a 220% increase in emergency medical calls since 1981 (Karter, Jr. & Molis, 2010). However, examining the number of injuries per 1000 non-fire emergencies reveals that the respective rate of injury has not increased; only the volume and the proportion of total injuries that emergency medical calls represent. Nonetheless, the absolute number of calls is greater and as such, the associated exposure to potential injury for firefighters responding to these calls.

The most common type of injuries experienced during both fire and non-fire emergency medical tasks are consistently strains or sprains. These types of injuries typically account for the greatest proportion of total injuries. Other categories of injuries include cuts and wounds, burns, smoke or gas inhalation, heat exhaustion, fractures and dislocations. (Karter, Jr. & Molis, 2010; United States Fire Administration, 2011). While the most common *type* of injury is a strain or sprain, the most common *cause* is overexertion, accounting for 25% of all injuries. Overexertion is determined as the root cause of an injury when the injury occurred during (or as a result of) a physical effort such as pushing, pulling, lifting or carrying (Karter, Jr. & Molis, 2010; Walton et al., 2003). This information is provided by two large investigations in which researchers collected firefighters' workers compensation claims, thus the term "overexertion" may be misleading as the exertion put forth when firefighters' were injured was never measured (Karter, Jr. & Molis, 2010; Walton et al., 2003).

Back Injuries in Firefighters

In 2000 the International Association of Firefighters (IAFF) reported that among professional firefighters nationally, the greatest proportion of all reported injuries were to the back (47%). The report went on to state that disability due to a back injury was the most often cited reason for early retirement among firefighters (International Association of Firefighters, 2000). Injuries to the arms, shoulders and chest accounted for 25% of reported injuries, while 12.2% of injuries affected the legs, hips and abdomen. However these injuries did not contribute to disability to the same extent as back injuries. The report is supported by several large research studies illustrating that back injuries account for a large proportion of injuries amongst this population (Cady, Bischoff, O'Connell, Thomas, & Allan, 1979; Cady, Thomas, & Karwasky, 1985; Walton et al., 2003).

The study by Walton suggests that back injuries not only occur frequently, they also incur greater financial costs to fire departments compared to other types of injuries.

Researchers collected firefighters' workers compensation claims from 77 fire departments between the years of 1992 and 1999. While they did not report the proportion of injuries which affected the back, in 1,343 claims, overexertion was the reported cause of a third of firefighters' injuries, and half of all overexertion related injuries were to the back (Walton et al., 2003). Further, back injuries are typically categorized as strains and most strain injuries cited in the claims (83%) were caused by overexertion. The United States Fire Administration collapses strain injuries and those caused by overexertion into one category. Thus it is likely that a great many of the workman's compensation claims resulted from a back injury and subsequent disability. To relate type of injury to relative costs, researchers reported that injuries caused by overexertion and those characterized as a strain were 89% and 80% more costly than other injuries, respectively. More specifically, the average workers compensation cost for overexertion related injuries (\$9,715) was nearly twice as high as the average cost for other injury categories (\$5,168). The mean expense for medical treatment per firefighter from overexertion-related injuries alone was \$319 per year (Walton et al., 2003).

While the aforementioned study illustrates that many workers compensation claims are due to back injuries and these are typically the most costly for fire departments, there also exists a cost incurred by filling a temporary vacancy when a disabling back injury has occurred. And while firefighters possessed the highest rates of injuries causing absenteeism compared to all other professions in both 2008 and 2009 (United States Bureau of Labor Statistics, 2010), the cost to fill vacancies (which typically requires that another firefighter be compensated at 1.5 times their normal pay rate) likely represents a considerable expense (National Institute of Standards and Technology, 2005).

Aside from a few cohort studies, there is little information to quantify the national financial impact of back injuries to the fire service. One longitudinal study on 1,652 firefighters in Los Angeles revealed that, between the years of 1973 and 1983, medical and payroll expenses resulting from injuries totaled 29.8 million dollars, 30% of which was attributable to back injuries (Cady et al., 1985).

Clearly, back injuries have been problematic in the firefighting population for many years. The high incidence of back injuries to firefighters is not surprising given the high-risk tasks they must execute as a function of their professional duties. One particularly high-risk task performed during fire suppression is handling a charged hose (a hose with water running through it); an activity during which 79% of all fire-related injuries occur (United States Fire Administration, 2011). However, injuries also occur due to postural contraindications related to handling a non-charged hose. In a study examining the postures adopted by firefighters during execution of typical tasks, researchers observed that even after a fire is suppressed, the overhead and bending activities involved in draining and rolling the hoses have great potential for injury (Gentzler & Stader, 2010).

Data suggest that the task most often resulting in a back injury is lifting patients during non-fire emergency medical procedures (Lavender, Conrad, Reichelt, Johnson, et al., 2000; Lavender, Conrad, Reichelt, Meyer, & Johnson, 2000; Walton et al., 2003). Non-fire emergency medical calls account for 20% of all calls and thus create considerable exposure to different injury risk scenarios for firefighters (Karter, Jr. & Molis, 2010). In the aforementioned worker's compensation claim study, lifting was reported as the specific cause of 49% of overexertion related injuries (half of which affect the back), and inadequate help/procedure for heavy lifting was also reported in 42% of the claims (Walton et al., 2003). While the proportion of emergency medical calls that result in lifting and transporting patients is unknown, firefighters have

reported that lifting patients is a task that they perform very frequently (Lavender, Conrad, Reichelt, Meyer, et al., 2000; Reichelt & Conrad, 1995)

Transporting patients involves several phases of lifting and carrying which results in multiple exposures to high-risk tasks from a firefighter's interaction with a single patient. Specifically, the task of "transporting" a patient involves 1) lifting the patient onto a gurney once arriving at the accident scene (this lift often emanates from an awkward body position where a patient may be stuck or have fallen); 2) lifting the gurney with the patient on it and carrying it to the ambulance; 3) further lifting the gurney and the patient up into the back of the ambulance; 4) lifting and transferring a patient from the fire department gurney onto a hospital gurney once at the emergency room. Thus, tending to one patient requires a great deal of lifting and carrying, and sometimes forces the firefighter to exert physical strength from a precarious body position.

Several well-designed studies by Lavender and colleagues show biomechanically just how hazardous transporting a patient can be for a firefighter's back (Lavender, Conrad, Reichelt, Johnson, et al., 2000; Lavender, Conrad, Reichelt, Meyer, et al., 2000) Researchers asked 374 firefighters to identify the tasks involved in emergency rescue situations which they believed to be most hazardous in terms of injury risk. Researchers then recruited seventeen male and three female firefighters from seven fire departments to perform the top five most hazardous work tasks (those that are both strenuous to perform *and* frequently performed) from the viewpoint of the firefighters. All of the tasks were involved in patient transport. The actual forces acting on the spine were measured during each task with the use of an electronic lumbar motion monitor which was strapped onto each firefighter (Lavender, Conrad, Reichelt, Johnson, et al., 2000). Ultimately, researchers found that the forces acting on the spine were near or above the safe limit of 3,434 Newtons (N) set by the National Institute of Occupational Safety and Health

(NIOSH). According to NIOSH, exceeding the safe limit requires implementation of administrative controls or job redesign. In fact, when leaning forward to lift a patient from a bed to a gurney, the average compression force found at the fourth and fifth lumbar vertebrae was 5476 N. While research has shown that the healthy young male spine can tolerate between 12,000 and 19,000 Ns of compression force in one load, this threshold likely lowers as a firefighter repetitively performs this lifting task. Also, a shear force of only 2000 N may result in fracture to the facet joints of the vertebrae. In vitro, herniation of the intervertebral disc has been observed when the spine is loaded with only 1,472 N and a flexion motion (like that performed when lifting a gurney) is repeated between 5,000 and 9,500 times (McGill, 2002). Thus it is likely the magnitude of forces produced by firefighting tasks such as patient transfer are sufficient to cause damage to the spine, especially over time.

Fitness and Risk for Back Injuries

Along with proper mechanics, improving or maintaining back strength and fitness is often promoted as a back injury risk reduction strategy for firefighters. Perhaps one of the earliest works addressing the problem of back injuries in firefighters was conducted between 1971 and 1974 at the Los Angeles fire department (Cady et al., 1979). Researchers stratified 1,652 firefighters into a least, middle or most fit group and found the incidence of back injuries to be 7.1%, 3.2% and 0.8% in the three groups, respectively. Measures of fitness included diastolic blood pressure and physical work capacity (watts) achieved during a twenty-minute bicycle ergometry test, two-minute recovery heart rate, spine flexibility and isometric strength. The five measurements were combined into a composite score and each firefighter was assigned to a fitness group based on percentiles; 84th percentile and above for most fit, 83rd to 17th percentile for middle fit, and 16th percentile and below for least fit, culminating into n=266,

n=1127, and n=259 firefighters in the three groups, respectively. While the most fit and least fit groups represented almost the same number of firefighters, the most-fit group sustained only two back injuries over the three-year period following the testing compared to nineteen back injuries in the least fit group. Therefore, the frequency of injury for the least fit firefighters was ten times more than for the most fit firefighters.

Further, the average cost per injury for the nineteen injured firefighters in the least fit group was 13% higher than for the thirty-six injured firefighters in the middle-fit group; there were too few injured firefighters in the most-fit group (n=2) to obtain a representative mean cost per injury for comparison (Cady et al., 1979). One limitation of this study is that researchers did not examine the relationship between each specific fitness test and back injuries; rather, they formed a composite fitness score for each firefighter and used this in their analysis. It would be meaningful to understand what aspects of fitness are most predictive of back injuries in order to develop effective strategies to prevent back injuries.

Cady also did a sub-study examining only those firefighters who had never experienced a back injury prior to the examination. In these several hundred firefighters, there were no back injuries over the ensuing three years in the most-fit group while one third of those in the least-fit group sustained a back injury (Cady et al., 1979). In a later publication, Cady reported results of another sub-study including 320 firefighters between the ages of 40 and 49 (Cady et al., 1985). From 1973 to 1982, the twenty firefighters with the highest spine flexibility scores had incurred only \$8,831 in costs due to back injuries compared to \$50,086 for the twenty firefighters who possessed the least spine flexibility. Similar but less dramatic differences were observed for the twenty strongest firefighters versus the twenty weakest incurring costs of \$10,992 and \$30,851 over the project period, respectively (and the authors reported that the strength assessments were “specially designed measured of back and leg strengths.” However,

the specific tests were not described. This was also true relative to firefighters' work capacity as assessed using a bicycle ergometer test. The twenty firefighters with the greatest work capacity incurred medical costs due to back injuries of \$5,975 versus \$16,475 accrued among those with the lowest work capacity.

While the available evidence suggests that fit firefighters experience fewer and less costly back injuries than their non-fit counterparts, there is inadequate data to confirm that improving fitness ultimately lowers injury risk for firefighters. Only four intervention studies have published injury data as a result of implementing fitness programs in fire departments (Cady et al., 1979; Hilyer, Brown, Sirles, & Peoples, 1990; Leffer & Grizzell, 2010; Peate, Bates, Lunda, Francis, & Bellamy, 2007). Two of the studies encompassed all components of fitness (Cady et al., 1979; Leffer & Grizzell, 2010), while one focused on only flexibility (Hilyer, Brown, Sirles, & Peoples, 1990), and the other on core strength (Peate, Bates, Lunda, Francis, & Bellamy, 2007).

In the study by Leffer and Grizzel (2010), the fire department implemented an intervention that included a counseling session with a physician subsequent to each firefighter's annual fitness and medical assessment. Firefighters (n=252) were given an individualized workout plan and strongly encouraged to exercise for thirty minutes, four to five times per week, but compliance was not monitored and there was no control group. Throughout the first year following the counseling, 19 fewer injuries occurred compared to the year prior, translating to 171 fewer lost work days and a savings of \$254,980. Throughout the second year, the department recorded an estimated 216 work days and \$322,080 saved. While researchers reported that the mean Body Mass Index (BMI) decreased from 36.7 to 35.5 ($p=0.05$) for the cohort of firefighters whose BMI was initially over 33 (n=39 or 15% of the sample), they did not provide the results of the stress tests, nor strength and flexibility tests that were conducted

annually. Thus it is not clear which components of the intervention might be responsible for the reduction in lost work days.

Hilyer and colleagues (1990) found that firefighters who participated in a stretching program for six months ($n=251$) incurred fewer lost work time costs on the order of \$150,000 compared to a control group ($n=218$) over the succeeding two years ($p=0.03$). Firefighters were granted 30 minutes during each work shift (every third day) to complete twelve stretches that targeted the low back, hamstring and shoulder muscles. Performance on four of six flexibility tests (sit and reach, shoulder flexion and extension, and knee flexion) improved as a result of the intervention ($p<0.01$), yet how the flexibility scores relate to injury is unknown.

In another intervention study within a large fire department ($n=433$), researchers implemented a testing protocol and fitness intervention focused on core strength (Peate et al., 2007). The testing protocol, called the Functional Movement Screen (FMS), is used by various health and fitness professionals and was originally created for athletes. Unfortunately, little scientific data is available to understand whether it is an effective tool for identifying injury risk. The seven-test screening is said to identify weaknesses and poor movement patterns that place a person at risk for injury (Cook, 2003). Results of the study revealed that increasing age and history of musculoskeletal injury (to any area) was associated with a lower score on the FMS by 0.04 and 3.44 points, respectively, out of 21 points possible ($p<0.001$). Following the screening, firefighters attended a three-hour seminar where they: 1) learned methods for achieving ergonomically safe body positions while performing commonly required job tasks and 2) learned and practiced a host of core strengthening exercises. After one year, absenteeism due to injury was 62% lower than in the year prior to the intervention ($p<0.01$) and fewer injuries to the back occurred compared to a historical control group ($p=0.024$). It is unclear to what degree the

ergonomic training versus core strengthening contributed to the lower injury incidence, and the researchers did not repeat the FMS after the intervention.

While the studies reviewed here provide a glimpse into the influence of exercise training on injury reduction, the question remains: what is the relationship between specific fitness scores and back injury? More importantly, which fitness tests are most effective at predicting injury risk? There are still a large number of firefighters getting injured on the job and while it appears that fitter firefighters may have a reduced risk, there are no specific tests available to identify that risk.

Fitness and Performance on Firefighter-Specific Tasks

While there are no identified tests that can be used to predict back injury risk, information is available regarding the relationship between fitness scores and the ability to perform firefighter specific job tasks (Michaelides, Parpa, Thompson, & Brown, 2008; Rhea, Alvar, & Gray, 2004; von Heimburg, Rasmussen, & Medbo, 2006; Williams-Bell, Villar, Sharratt, & Hughson, 2009).

Twenty firefighters (17 male, 3 female) participated in a firefighter specific physical ability test (AT) along with a host of physical fitness tests. Researchers found that performance on four job tasks from the AT (hose pull, victim drag, stair climb and equipment hoist) correlated with two strength tests: bench press ($r=-0.66$) and hand grip, ($r=-0.71$); several muscular endurance tests: bent over row ($r=-0.61$), bench press ($r=-0.73$), shoulder press ($r=-0.71$), bicep curl ($r=-0.69$), and squat ($r=-0.47$); and the 400-meter run test for anaerobic endurance ($r=0.79$; all significant at $p \leq 0.05$.) The squat was the only strength test to challenge the lower body and it did not correlate with performance. The 12-minute run for cardiovascular endurance and the

abdominal curl test also did not relate to scores on the AT. This study did not include flexibility tests (Rhea et al., 2004).

In a similar study utilizing thirty-eight volunteer firefighters, time on a firefighter AT correlated with performance on a 1-repetition maximum (1 RM) bench press (a measure of upper body strength; $r=-0.44$) and a push-up test (upper body endurance; $r=-0.41$). Scores on the sit-and-reach, sit-up test and a 1 RM squat did not correlate with job performance. However, in multiple regression analysis, the sit and reach and squat tests were included in a model with the bench press that predicted 55% ($R^2=0.55$; $p<0.05$) of the variation in AT time. This study did not include a cardiovascular endurance test (Michaelides et al., 2008).

More recently, Williams-Bell found that a handgrip strength test was the only fitness variable, other than body mass and maximal oxygen uptake (VO_{2max}), to predict time to completion ($R^2=0.71$) for fifty-seven individuals who underwent the Firefighter Candidate Physical Ability Test (CPAT); the AT test endorsed by the IAFF (Williams-Bell et al., 2009). In another study, fourteen volunteer firefighters completed a simulated rescue by dragging patients out of a six-story building wearing 37 Kg of protective gear (von Heimburg et al., 2006). Firefighters who finished the task in 6 minutes or less had higher upper body strength (bench press), but not lower body strength (leg press), than firefighters who required 6.5 minutes or more to finish the task ($p=0.05$). Taken together, these studies illustrate that upper body strength and endurance appear to be most predictive of job performance for firefighters while flexibility and both aerobic and anaerobic endurance may also contribute to the ability to perform firefighter specific tasks. If upper body strength assessments are most predictive of job performance perhaps they are also predictive of injury on the job. However this has never been assessed. Furthermore, flexibility is not specifically tested in firefighter physical ability tests. As

such, firefighters may not be motivated to improve flexibility to perform their jobs well which would be detrimental if flexibility does in fact relate to injury risk.

Considering the literature, one might assume that fitness mitigates the risk of injury since fit firefighters tend to out-perform non-fit firefighters. Yet, to date, there are no studies which identify specific measures of fitness that predict a firefighter's risk for back injury.

Selecting a Test Battery

Although a few researchers who have investigated the relationship between fitness and injury have included tests for cardiovascular fitness (Cady et al., 1979; Leffer & Grizzell, 2010), few have examined solely the relationship between musculoskeletal fitness and injury (Hilyer, Brown, Sirles, & Peoples, 1990). Considering the principle of specificity, it's surprising that there have not been more studies examining the relationships between back strength, endurance, and flexibility and back injury.

Some research exists supporting a relationship between firefighters' trunk flexibility and their risk for back injury (Cady et al., 1985; Cowen, 2010; Hilyer, Brown, Sirles, & Peoples, 1990). Discussed earlier, Hilyer and colleagues found that firefighters developed better flexibility of the trunk, shoulders and knees and experienced fewer lost work days after participating in a 6-month stretching program, although the proportion of total injuries that affected the back was not reported (Hilyer, Brown, Sirles, & Peoples, 1990). In addition, Cady et al illustrated that Los Angeles firefighters who exhibited the highest spine flexibility scores incurred much lower medical costs due to back injuries compared to those with the lowest spine flexibility scores (Cady et al., 1985).

If possessing adequate flexibility is important for avoiding a back injury, tests for spine flexibility may help predict a firefighters' risk for a back injury. A test for lumbar flexion and

extension range of motion called the *Modified-Modified Schober test* has shown promise in terms of predicting low back pain development in a variety of manual labor workers (Hess & Hecker, 2003). The Schober test requires a simple tape measure to assess range of motion in the lower back while participants flex and extend their lumbar spines (Tousignant, Poulin, Marchand, Viau, & Place, 2005). Another test which involves spinal extension is the YMCA chinup test in which participants lie prone and attempt to raise their trunk and chin as high as possible without using their arms. We hypothesized that this test may be promising for identifying deficits in performance that are associated with back injuries since it challenges the back extensor muscles while simultaneously requiring some range of motion in spinal extension. Our final assessment of spine flexibility, a trunk rotation test, was included in the testing protocol in the studies conducted by both Hilyer and Cady, in which an overall reduced injury incidence was associated with improved/adequate flexibility. However, trunk rotation has not been analyzed for its direct influence on back injuries.

Aside from flexibility, muscular strength and endurance may be important indicators of back injury risk (Cady et al., 1985). However, there are no data relating back strength and endurance specifically to back injury among firefighters. Furthermore, in studies where firefighters' fitness is related to job performance, typically the only assessment of lower body strength is a squat. A squat challenges primarily the quadriceps and the gluteal muscles yet the hamstrings are likely equally important during firefighter tasks. Since the hamstrings are hip extensors, and the hips must be extended in order for one to stand up straight, these muscles become highly active when a firefighter lifts a heavy gurney in front of his or her body. If the hamstrings are weak, the spine may be forced into flexion. This position exponentially increases pressure in the joints of the spine (Neumann, 2010). To this author's knowledge, a test of hamstring strength or

endurance has never been included in a study assessing the relationship between fitness and injury in firefighters.

Given that a host of performance studies present data indicating upper body strength and endurance is most important when performing firefighting tasks, and lifting is the primary activity responsible for back injuries outside of fire suppression, understanding one's upper back fitness may be promising in terms of estimating back injury risk. Although Rhea et al. (2004) found that the bent over row test assessing back muscle endurance was associated with job performance, it has never been considered as a screening test for injury. Also, a static upper back strength test using dynamometry was included in Cady's landmark study but it also has never been considered as a screening test for injury. Considering that a biomechanical analysis of tasks involved in patient transfer reveal that the upper body plays a prominent role in executing these tasks and the resultant muscular demands appear to be quite strenuous (Lavender, Conrad, Reichelt, Johnson, et al., 2000), it is plausible that upper body strength and endurance are important indicators of a firefighter's risk of becoming overexerted and consequently injured on the job. Thus, the bent over row and static upper back strength tests have been chosen as a part of the current test battery.

Thus, we propose that a screening battery including three spinal flexibility tests, a test of hamstring strength, a static back strength test and a bent over row test may provide useful data regarding a firefighter's risk for experiencing a back injury. The adoption of these six assessments of trunk flexibility and strength are justified by the evidence that firefighters with a history of back injury tended to score lower on the FMS than those who were free from injuries (Peate et al., 2007). The FMS tasks individuals to move throughout a full range of motion while performing exercises, such as a squat, in which body weight acts as resistance. A low score on the FMS may be an indication that a firefighter lacks flexibility and/or strength in key areas like

the hamstrings and upper back, as such limitations may inhibit proper mechanics and place the back at greater risk for injury. However, unlike the tests in the battery we have identified, the FMS does not identify a specific region (back, legs, etc.) or mechanism (strength, flexibility) that could subsequently be targeted for rehabilitation.

Perception of Fitness

Factors related to the way firefighters behave in relation to their fitness levels may also contribute to their risk for injury. Behavior is driven by a multitude of influencing factors, among them, our outcome expectations related to participating in a particular behavior (Bartlett, Li, & Zhang, 2007). As an example, if an individual believes they are not strong enough to participate in a particular behavior (lift a body onto a gurney by themselves), they may refrain from that behavior to avoid harm. On the other hand, if they believe they are strong enough, they may be more likely to attempt the behavior. Research shows that firefighters do indeed believe specific factors related to physical abilities can affect their susceptibility to injury (Reichelt & Conrad, 1995). In a series of focus groups, Reichelt and Conrad (1995) queried thirty-nine firefighters from fourteen different departments about their perceptions surrounding on the job injuries. As a whole, the firefighters identified factors relating to physical capacity such as fitness level, fatigue and skill level to be the primary determinants of injury that are unique to each individual. Particular to the workplace, firefighters responded that working in confined, awkward spaces and interacting with heavy equipment were related to injury risk along with whether the department offered a fitness program (Reichelt & Conrad, 1995). However as in the scenario described above, whether firefighters' perceived susceptibility to being injured influences their physical behaviors at work and affects injury risk independent of physical fitness is unknown.

This author has gleaned by working with firefighters that some feel it is important to maintain a high level of fitness in order to protect their peers from injury (since many tasks in the fire service require that firefighters work as a team and rely on one another's physical capabilities). Additionally, firefighters who feel they are more physically capable than other firefighters have shared that they choose the most physically demanding position during a lifting task (personal communication).

This tendency toward adapting behaviors related to physical capacity based on an individual's perceived capacity has been explored, though not among firefighters (Bartlett et al., 2007). Study participants included 16 men and 16 women ranging in age from 20 to 41 years; all were asked to complete a task that required moving a stack of weights from one location to another. Participants were first measured on four isokinetic strength tests in which joint rotation speed was controlled at 60°/s on a Biodex system. Participants were not informed of their performances prior to completing the strength task. Generally, individuals who scored well on the strength tests chose to carry more weight per lift than did weaker individuals (Bartlett et al., 2007). Although this may not seem particularly surprising, it demonstrates that even though participants were told to take as much time as needed to complete the task, the stronger individuals chose a strategy that was more risky in terms of injury. In a second aim of the study, researchers investigated whether knowledge of strength mediated lifting strategies. While all participants underwent the strength testing, one group of individuals was given feedback about their strength level (relative to other participants in the study and the general population) prior to performing the lifting task while a second group was not given feedback. All individuals who received feedback about their strength tended to lift more weight per carry than did individuals without feedback, and this was especially true for weaker individuals. For

the latter, the impetus to perform well after being informed that their strength was poor may have outweighed the desire to protect themselves from injury, however this was not measured.

The factors influencing physical activity behavior among firefighters have been explored by a handful of researchers (Elliot et al., 2004; Kipp, 2008). The relationship between perceived fitness, performance, and injury risk has never been addressed. One might assume that firefighters who perceive themselves as fit are more likely to engage in activities that increase their risk for injury, particularly given the anecdotal evidence provided earlier that firefighters who perceive themselves to be stronger than others self-select the tasks that are most difficult. However, as the study by Bartlett et al (2007) suggests, individuals who were told that they lacked strength self-selected to move more weight in a single lift than individuals who were not. This appears contrary to what the anecdotal evidence may suggest, but again, this has never been explored. However, it is possible that firefighters who are not fit, but perceive themselves to be fit, or possess a desire to show that they are not weak may be most injury prone. Potentially, firefighters who possess high perceived fitness but low actual fitness may be at an additional risk of injury compared to firefighters whose perception of their fitness level is more closely aligned with their actual fitness level. Firefighters in the former group may be electing to perform physically demanding tasks without sufficient strength or flexibility to perform them safely, thereby increasing their risk of experiencing an injury.

Toward this end there have been a handful of studies examining firefighters' perceptions of their fitness in comparison to actual fitness (Peate, Lundergan, & Johnson, 2002; Saborit et al., 2010). Results from both of these studies suggest that perceived fitness and actual fitness do not align among the firefighters studied. For instance, in a group of 37 firefighters who completed a perceived fitness survey and performed a graded exercise test, almost all of the men with an aerobic capacity lower than that deemed sufficient for firefighting (42

ml/Kg/min) reported that they thought they had “high” or “very high” cardiovascular endurance (Saborit et al., 2010). In a similar study, Peate and colleagues found a lack of association between firefighters’ measured aerobic capacity and self-reported physical fitness level ((Peate, Lundergan, & Johnson, 2002).

The limitations of these studies support the need for further investigation as neither study utilized a validated measure of perceived fitness to assess firefighters’ perception of their fitness. In fact, Peate et al. utilized a questionnaire that required firefighters to rank their fitness level on a scale from 0 to 7; “I avoid walking or exertion...” was the response associated with a ranking of 0 and “I run over 10 miles per week...” was the response associated with a ranking of 7. It appears that while these authors claimed to have measured firefighters’ perception of their fitness level, they actually measured firefighters’ perception of their activity level. The same questionnaire was adapted for use in the study by Saborit (2010). Each response from 0-7 was expanded upon to include perceptions regarding aerobic capacity; firefighters were asked to answer “0” if they felt their aerobic capacity was low, “4” if it was normal, “5” if high, “6” if very high and “7” if excellent. Furthermore, neither study assessed firefighters’ perceptions of their musculoskeletal fitness (muscular strength, muscular endurance and flexibility). Thus, the relationship between firefighters’ perceptions of their physical strength and their actual musculoskeletal fitness is unknown. Moreover, no information is available regarding firefighters’ perceptions of their fitness level and their history of injuries. Yet, this information could be invaluable for understanding how firefighters’ behavior when faced with a risky physical task is influenced by how strong and well-conditioned they believe themselves to be. If injuries are occurring in those firefighters who are not physically superior over their peers but believe themselves to be, this could help inform the development of an intervention to lower incidence of back injuries in firefighters.

Firefighters and Heart Attacks

Injuries are not the only on-the-job risk faced by firefighters. Nearly half of all on-duty firefighter deaths result from heart attacks and many non-fatal cardiac events also occur each year (Soteriades et al., 2011). Since the greatest predictor of death from a cardiac event on the job is a previous diagnosis of CHD (Geibe et al., 2008), the risk factors for fatal heart attacks in firefighters are analogous to those for CHD. It is well established that low cardiorespiratory fitness, in addition to hypertension, smoking, high cholesterol, diabetes and obesity are major risk factors for CHD-related death for all individuals (Lloyd-Jones et al., 2010). Fitness in particular, which as described is an important factor for job performance among firefighters, is also highly correlated to CHD risk. In normal weight men, the relative risk of death from CHD is 3.1 times higher for men who possess low cardiorespiratory fitness compared to those who do not, as assessed by maximal graded exercise tests (GXT) and age specific criteria for maximal oxygen uptake (VO_{2max} ; where low fitness is characterized as a $VO_{2max} < 36.75$ ml/kg/min for 20-39 years of age, < 34.65 ml/kg/min for 40-49 years of age, < 30.8 ml/kg/min for 50-59 years of age and < 26.25 for ≥ 60 years of age; (Wei et al., 1999). However, positive changes in fitness can substantially reduce CHD risk as evidenced by results from a prospective study of 9,700 men, showing that for every minute improvement in time to exhaustion on a GXT, all-cause mortality decreased by 8% (Blair et al., 1995).

Unfortunately, a longitudinal study to estimate the influence of cardiorespiratory fitness on the incidence of heart attacks in firefighters has not been conducted, but several researchers have illustrated that possessing high cardiorespiratory fitness induces positive effects on other CHD risk factors in the firefighting population (Baur, Christophi, Tsismenakis, Cook, & Kales, 2011; Durand et al., 2011; Geibe et al., 2008). In 968 male firefighters who underwent maximal

GXTs, increasing VO_2max was associated with decreased resting diastolic blood pressure ($p<0.01$), total cholesterol/HDL ratio ($p<0.01$) and fasting blood glucose ($p=0.03$), and increased HDL-cholesterol ($p<0.01$), independent of age and BMI (Baur et al., 2011). With the same cohort of firefighters, Durand found that frequent (self-reported) participation in exercise, which was associated with higher cardiorespiratory fitness, had similar favorable effects on CHD risk factors and these effects were consistent across all BMI categories (Durand et al., 2011).

Firefighters who participate in frequent exercise and are aerobically fit may experience a two-fold benefit toward a reduced risk of heart attack. As discussed, they exhibit improved CHD risk factors. Also, it is hypothesized that they experience less physical stress during the unpredictable, intense bouts of exertion that firefighters frequently encounter on the job (Soteriades et al., 2011). Several researchers have illustrated that these bouts of exertion can be very strenuous (Holmer & Gavhed, 2007; von Heimburg et al., 2006; Williams-Bell et al., 2009). During simulated emergency scenarios which typically include running, walking, crawling, climbing stairs, and pushing, pulling and carrying objects, often wearing 37 Kg of protective gear, firefighters' have exhibited a mean oxygen uptake of 31.54 ± 10.60 ml/kg/min (Elsner & Kolkhorst, 2008), 38.5 ± 5.3 ml/kg/min (Williams-Bell et al., 2009), 42.7 (Holmer & Gavhed, 2007), and 44 ± 5 ml/kg/min (von Heimburg et al., 2006), measured using portable metabolic equipment. The most physically demanding tasks for firefighters are associated with fire suppression. Accordingly, the greatest proportion of fatal CHD-related heart attacks (32%) occur while suppressing a fire (relative to other undertakings such as training activities and emergency medical calls). In fact, risk of death from a CHD-related heart attack is between 10 and 100 times higher during fire suppression compared to non-emergency tasks ((Kales et al., 2007). Based on these observations, a minimum VO_2max of 42 ml/kg/min is recommended by the IAFF on the assumption that firefighters who do not meet this threshold may experience physical

overexertion on the job that would put them at increased risk for heart attack (International Association of Firefighters, 1997). Thus, it is vital that all firefighters undergo regular VO_2max testing.

Assessing Maximal Oxygen Uptake in Firefighters

Recently a prediction equation was developed for estimating VO_2max using a simple GXT which requires firefighters to run on an incline and can be conducted on a standard treadmill (Tierney, Lenar, Stanforth, Craig, & Farrar, 2010). The “Gerkin protocol” proves beneficial for fire departments in that the tests can be conducted in-house, and the corresponding prediction equation has a relatively small standard error (3.7 ml/kg/min). However, some firefighters who suffer from pain in the back, hips or knees are not able to participate in a running test without exacerbating their symptoms, which is not surprising given the high incidence of musculoskeletal injuries in the firefighting population.

There are other GXT protocols available that do not require running, including some utilizing elliptical trainers (Dalleck, Kravitz, & Robergs, 2006) and cycle ergometers (Gordon, 2009), and some submaximal walking protocols (Ebbeling, Ward, Puleo, Widrick, & Rippe, 1991; Larsen et al., 2002). However, a few limitations exist for using these protocols in a firefighting population. Since the purpose of the GXT is to determine whether firefighters are physically able to perform their jobs safely, it should simulate the actual job tasks of a firefighter as much as possible; consequently the treadmill is more appropriate than a cycle ergometer as the mode of exercise.

Furthermore, it is inappropriate for firefighters to undergo submaximal GXTs (from which VO_2max is predicted) since the job often requires near maximal exertion and the stress test is liable to produce false negative results if dangerous cardiac arrhythmias are only evident

at high intensities. Thus, an optimal test for firefighters who cannot run is one that evokes a maximal effort by walking on a treadmill, yet to our knowledge, such a protocol does not exist.

Developing a walking protocol that evokes a maximal effort will be challenging if firefighters who cannot run are still aerobically fit. It is possible that firefighters who experience joint pain while running participate in other forms of exercise such as biking or swimming, in which case, an individual may possess high cardiorespiratory fitness. As such, a walking test protocol would require an approach to increase the intensity sufficiently via strategies other than increasing walking speed to a run. One method for increasing the intensity of a walking test which has been utilized in wildland firefighting is to incorporate a weighted pack. The most widely used applicant screening test for wildland firefighters is called the “Pack test” in which individuals must walk three miles carrying a backpack weighing 20.4 Kg in 45 minutes or less. The pack test is conducted on flat ground and not on a treadmill. Laboratory tests have validated that the Pack test simulates the aerobic and muscular demands of wildland firefighting which is characterized by walking with a pack, digging fire lines and pulling charged hoses. The estimated VO_2max of individuals who can complete the test in 45 minutes is 45 ml/kg/min and this has been shown to be adequate for wildland firefighting through direct gas analysis (Sharkey & Davis, 2008).

While the Pack test is an appropriate job-related test for wildland firefighters, it does not simulate structural firefighting well since the latter involves lifting and carrying guineys and forcing entries into buildings, and is comprised of long periods of rest combined with short periods of exertion. Further, since it is not used to predict VO_2max (only whether the applicant is below or above 45 ml/kg/min) firefighters who undergo the Pack test gain little information about how their aerobic capacity relates to their peers, to their own health and specifically to their risk for heart attack. Thus, it will not work well for our purposes. However, like wildland

firefighters, structural firefighters wear heavy clothing and gear. In fact, during the CPAT which has been validated for structural firefighting, applicants wear a vest weighing 22.7Kg for eight tasks plus additional weight totaling 34.1 Kg for the final stair climb task (Sharkey & Davis, 2008). Hence, for firefighters who cannot run, a VO_2 max test with a weighted vest may be ideal in that it is job-specific and would only require walking but would still be challenging. It could be conducted in-house, with an ECG, and it would be less time consuming than the Pack test given that the treadmill will allow for grade increases which would also increase intensity. To this end, there is a need to develop and administer a laboratory-based maximal treadmill test that utilizes a graded walking protocol and a weighted vest to alter intensity in order to develop an equation for estimating firefighters' VO_2 max from their performance on the walking treadmill test.

The overall objective of this dissertation is to address some of the identified gaps in the literature with a purpose of developing screening tests to predict whether a firefighter is at risk of experiencing an adverse event on the job. Adverse events specifically of interest in this dissertation are back injuries and heart attacks. In order to address this topic there is a need to understand how performance on fitness tests relates to several outcomes, including back injuries, perceived fitness, and maximal aerobic capacity among firefighters. These data will inform the development of predictive tests that may be performed by all firefighters on duty, with minimal equipment, time or financial cost to departments.

The purpose of the first study was to investigate the relationships between firefighters' history of back injuries and their scores on tests of back strength and endurance, hamstring strength and spine flexibility in order to identify potential injury screening tests for use in the firefighting population.

The goal of the second study was to examine the relationships between firefighters' perceptions of their strength and overall conditioning and history of back injuries. This information could help us understand if firefighters' injury risk is affected by how fit they believe themselves to be, and whether these beliefs influence the relationships between fitness and risk for back injury, which could ultimately inform the development of an intervention to lower incidence of back injuries in firefighters.

The third and final study involved the development of a treadmill walking protocol to predict VO_2max in firefighters. Given the high incidence of cardiac events in the fire service and the tight relationship between aerobic fitness and risk for heart attack, it is imperative that screening tests be available to help firefighters understand their risk. However, these assessments must be feasible for fire departments to implement with respect to financial and personnel constraints; they must be able to be conducted in-house, be minimally invasive, take little time, be relevant for all duty-fit firefighters, and ideally, be job-specific. Thus, the purpose of the last study was to develop a walking test using a weighted vest, which can be carried out on a standard treadmill, to predict VO_2max in firefighters.

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CHAPTER TWO

RELATIONSHIPS BETWEEN SPECIFIC BACK-FITNESS TESTS AND THE OCCURRENCE OF BACK INJURIES IN FIREFIGHTERS

Submitting to the *Journal of Occupational and Environmental Medicine*

ABSTRACT

Firefighters experience a high incidence of back injuries; approximately 50% of firefighters will have at least one back injury during their career. Back injuries are cited as the primary reason for early retirement from disability. An assumption exists that fit firefighters endure fewer back injuries, yet the true relationship between firefighters' fitness level and incidence of back injury is understudied. It is not clear what specific aspects of fitness may contribute to the occurrence of back injuries or what tests may predict a firefighter's risk of experiencing a back injury.

Purpose: To investigate the relationships between specific back-fitness tests and the occurrence of back injuries in firefighters. **Methods:** Firefighters from three fire departments (n=113) completed a back injury survey and participated in eight back-fitness tests: A *Modified-Modified Schober test* for lumbar flexion and lumbar extension, a trunk rotation flexibility test, a back endurance "row" test, a back strength test, a hamstring strength test and a prone chin-up test. Firefighters were surveyed about the number of back injuries they had sustained throughout their careers and other relevant parameters. A zero-inflated Poisson (ZIP) regression analysis was used to investigate the relationship between scores on the back fitness tests and firefighters' history of back injuries. To account for exposure time, number of years as a firefighter was included in the model. **Results:** The firefighters' mean age and years on the job were 37.7 ± 8.8 and 11.8 ± 8.5 , respectively. Fifty-one percent (n=58) of the firefighters reported

experiencing at least one back injury. Of those, 24 (21%) reported one injury, 14 (12%) reported two and 20 (18%) reported 3+ back injuries. For every one centimeter increase in lumbar extension flexibility the expected number of back injuries increased by 52.1% ($p<0.01$). No significant relationships emerged between number of back injuries and scores on the remaining fitness tests ($p>0.05$). **Conclusion:** Possessing limited lumbar extension flexibility is associated with a lower risk for back injuries among our sample of firefighters. However, a prospective study is needed to determine whether lumbar extension flexibility predicts future back injuries among firefighters.

Key Words: firefighters, back injuries, fitness tests

INTRODUCTION

Firefighting is a very hazardous profession. Recent data from the US Bureau of Labor Statistics illustrates that firefighters are three times more likely to become injured on the job compared to workers in the agricultural, manufacturing and construction trades. Furthermore, firefighters consistently possess the highest rates of injury-related absenteeism than those in any other profession (U.S. Bureau of Labor Statistics, 2011).

The injuries of greatest concern are those to the back because these are the mostly frequently occurring, most costly and most debilitating type of injury experienced by firefighters. According to the International Association of Firefighters (IAFF), the greatest proportion of all reported injuries are to the back (47%) and back injuries are the most often cited reason for early retirement among firefighters (International Association of Firefighters, 2000). A back injury can be challenging or worse, career ending for a firefighter who is expected to perform the physical demands required of the job despite injury-related chronic pain.

Research suggests that back injuries result in greater financial burden for fire departments compared to other types of injury (Cady, Thomas, & Karwasky, 1985; National Institute of Standards and Technology, 2005; Walton, Conrad, Furner, & Samo, 2003). Walton and colleagues collected 1,343 firefighters' workers compensation claims from 77 fire departments and reported that the average workers compensation cost for injuries caused by overexertion (half of which were back injuries) was nearly twice as high as the average cost for other injury categories (Walton et al., 2003). Indirect costs of back injuries among firefighters include human resource outlays due to temporary vacancies when a full time firefighter incurs a disabling back injury. Such vacancies often require that another firefighter be compensated at 1.5 times their normal pay rate, a considerable expense for fire departments; many of which are already under resourced and may be unable to absorb these costs (National Institute of Standards and Technology, 2005). Although there is not enough information to quantify the financial impact of back injuries to the fire service generally, one ten-year investigation including 1,652 firefighters in Los Angeles revealed that 30% of a total 29.8 million dollars in injury related expenses was attributable solely to back injuries (Cady et al., 1985).

The high incidence and severity of back injuries to firefighters is not surprising given the physically strenuous tasks they must execute as a function of their professional duties. Several biomechanical studies have illustrated that firefighting tasks associated with both medical aid (Lavender, Conrad, Reichelt, Johnson, & Meyer, 2000; Lavender, Conrad, Reichelt, Meyer, & Johnson, 2000) and fire suppression (Gentzler & Stader, 2010) place very high forces on the spine; forces that are in fact greater than the highest acceptable level as established by the National Institute for Occupational Safety and Health (Lavender, Conrad, Reichelt, Meyer, et al., 2000). One particularly high-risk task performed during fire suppression is handling a charged hose (a hose with water running through it); an activity during which 79% of all fire-related

injuries occur (United States Fire Administration, 2011). Even after a fire is suppressed, the overhead and bending activities involved in draining and rolling the hoses have great potential for injury (Gentzler & Stader, 2010). During non-fire emergency medical calls, data suggest that the task most often resulting in a back injury is lifting patients (Lavender, Conrad, Reichelt, Johnson, et al., 2000; Lavender, Conrad, Reichelt, Meyer, et al., 2000; Walton et al., 2003). In the aforementioned worker's compensation claim study, lifting was reported as the specific cause of 49% of overexertion related injuries (half of which were back injuries). Inadequate help/procedure for heavy lifting was reported in 42% of the claims suggesting many back injuries due to lifting may be preventable (Walton et al., 2003). While the proportion of emergency medical calls that result in lifting patients is unknown, firefighters report that lifting patients is a task that they do frequently as a function of their job responsibilities (Reichelt & Conrad, 1995).

Since firefighting is known to be a physically demanding profession, there has been a long held assumption that firefighters who possess ample strength and flexibility are at a reduced risk for injury. However, only a few researchers have actually investigated this (Cady, Bischoff, O'Connell, Thomas, & Allan, 1979; Hilyer, Brown, Sirles, & Peoples, 1990; Peate, Bates, Lunda, Francis, & Bellamy, 2007). Cady and colleagues conducted fitness assessments on Los Angeles firefighters between 1971 and 1974. Firefighters were stratified into tertiles based on an aggregate of scores from several different health and fitness assessments (diastolic blood pressure and physical work capacity achieved during a twenty minute bicycle ergometry test, two-minute recovery heart rate, spine flexibility and isometric strength). Among firefighters who had no history of back injury prior to study enrollment, one-third of those in the least-fit tertile sustained at least one back injury during the three-year prospective study, compared with no injuries among firefighters in the most fit tertile (Cady et al., 1979). While this investigation

suggests an association between fitness and back injuries, practical application of these results are limited since targeted risk reduction strategies are difficult to develop without an understanding of which fitness components contributed most to back injury risk. Two studies have included more targeted programs focused on stretching (Hilyer et al., 1990) and core strengthening (Peate et al., 2007) and authors reported reduced injury rates subsequent to these targeted interventions. However, in the first study by Hilyer, the relationships between flexibility scores and injuries were not analyzed so we do not know whether improved flexibility actually led to the reduced injury rate (Hilyer et al., 1990). The second study by Peate should be interpreted with caution because it did not include a control group (Peate et al., 2007).

Thus, sufficient evidence to conclude that fit firefighters are at a reduced risk of experiencing a back injury is lacking. Furthermore, there has never been an investigation to understand how performance on individual fitness tests (as opposed to aggregated test scores) relates to the occurrence of injury. As such, there is a need to identify fitness tests that can be used to screen and/or predict firefighters' risk for injury.

The existing studies that have identified the actual tasks that place firefighters at high risk for back injury (handling hoses and lifting patients) (Gentzler & Stader, 2010; Lavender, Conrad, Reichelt, Johnson, et al., 2000; Lavender, Conrad, Reichelt, Meyer, et al., 2000; Walton et al., 2003) point to upper body strength as a potential indicator of risk since these tasks rely heavily on exertion of the upper body musculature. This notion coincides with what has been observed when authors have investigated the relationships between fitness assessments and job performance involving completing tasks such as dragging victims, climbing stairs, and hoisting equipment overhead, as quickly as possible. Consistently, scores on tests of upper body strength such as bench press (Michaelides, Parpa, Thompson, & Brown, 2008; Rhea, Alvar, & Gray, 2004; von Heimburg, Rasmussen, & Medbo, 2006), grip strength (Rhea et al., 2004; Sheaff

et al., 2010; Williams-Bell, Villar, Sharratt, & Hughson, 2009), chest press (Sheaff et al., 2010), and bent-over-row (Rhea et al., 2004) relate to job performance, while lower body muscular fitness as assessed by a squat (Michaelides et al., 2008; Rhea et al., 2004), leg press (Sheaff et al., 2010; von Heimburg et al., 2006; Williams-Bell et al., 2009) or sit-and-reach test (Michaelides et al., 2008), does not.

As such, we postulate that upper body strength assessments, particularly tests specific to back strength and endurance, may provide the best indication of back injury risk in firefighters. We also hypothesize that leg strength is related to injury risk since it plays a role in execution of lifting tasks, and that a test of hamstring strength may be a better indicator of injury potential compared to a squat or leg press test. Since the trunk partially relies on the hamstrings to maintain upright posture and avoid injury during a lifting task, it is possible that hamstring strength plays a more important role in injury risk for firefighters compared to quadriceps strength. We further hypothesize that spine flexibility may be an indicator of injury risk since it is required for trunk flexion when rolling up hose and lifting patients from precarious positions. Therefore, the purpose of this study was to investigate the relationships between firefighters' history of back injuries and their scores on tests of back strength and endurance, hamstring strength and spine flexibility.

METHODS

Design

This was a cross-sectional study conducted at a fire station in each of three urban fire departments in Oregon. Approximately 250 career firefighters were invited to participate. This study was approved by the Oregon State University Institutional Review Board and all participants gave written informed consent prior to participation.

Procedures

A total of 113 male firefighters completed a survey about their history of injury on the job and subsequently participated in six short fitness assessments on duty. Firefighters who reported suffering from neck, back or leg injuries at that time were excluded.

History of Injury Survey: The history of injury survey was an 11item questionnaire developed to gather information about the number and type of injuries experienced by firefighters participating in the study. Specifically, firefighters were asked to report if they had suffered from 0, 1, 2 or 3+ back injuries throughout their careers. They were also asked to report the nature and cause of their back injuries and their age and number of years on the job. The criteria for determining whether a firefighter had experienced an injury was a “yes” response on the following survey question: “Assume that a ‘back injury’ describes something that happened **at work only** that resulted in moderate to severe pain in your back for a prolonged period of time. These may or may not be injuries that caused you to miss work days. In that sense, have you ever experienced a back injury while on duty as a firefighter?” This was a self-report measure and was not validated against injury records as they were not made available to us by the fire departments.

Fitness Assessment Test Battery: Firefighters performed a 5-minute warm-up that consisted of walking outside or on a treadmill, and then completed the following fitness tests organized as a circuit:

Chin-up Test. This test assesses back flexibility in extension. Participants were required to lie face down on a mat, with hands resting by their sides. Without using their hands,

participants were asked to slowly arch their back so their head and chest rose off the ground while looking forward and keeping their chin level. The distance that participants raised their chin off the floor was measured using a yardstick and recorded to the nearest quarter of a centimeter. This test is part of the YMCA FITNESSGRAM protocol and has been validated against goniometer measurements of trunk flexibility ($r=.7$). Reliability is .9 for a single trial test (Patterson, Rethwisch, & Wiksten, 1997).

Trunk Rotation Test (Figure 1). This test measures spine flexibility in axial rotation. Participants sat in a chair with a Velcro strap wrapped around their chest, with a dowel protruding from the sternum. Their arms rested over a dowel placed across the shoulders. The trunk rotation measurer, which resembled a table with a semicircle cut out of it, was placed in front of each participant. They then rotated as far as possible to each side while the researcher measured the distance traveled by the chest dowel to the nearest degree. This test was previously utilized in a study in which an aggregate fitness score was associated with back injury incidence in firefighters (Cady et al., 1979). There are no estimates of validity and reliability for this test.

[Insert Figure 1]

Lumbar Flexibility Test (Modified-Modified Schober test). This test measures flexibility of the lumbar spine in flexion and extension. The examiner first marks the participants back at the base of the lumbar spine and 15 cm above the first mark using a cloth measuring tape. To assess spinal flexion, participants began from a standing position with shoulders aligned over the hips. Participants were instructed to bend forward at the waist as far as possible allowing their lumbar spine to flex. The new distance created between these two marks was measured

and recorded to the nearest quarter of a centimeter. Greater range of motion in spinal flexion is indicated by larger values. To assess spinal extension, participants began from upright standing with shoulders and hips aligned, and were instructed to bend backward at the waist while allowing the pelvis to move anteriorly. Increasing range of motion in spinal extension resulted in the marks becoming closer to one another. Therefore, the new distance between the two marks was subtracted from 15 cm so that larger values indicated greater spinal extension flexibility. This test has been validated against x-ray measurements of lumbar spine flexibility ($r=.67$) and intra-tester reliability is .95 (Tousignant, Poulin, Marchand, Viau, & Place, 2005)

Hamstring Strength Test (Figure 2). This test assesses muscular fitness of the hamstrings. Participants sat on the edge of a bench or chair with a resistance band of known resistance secured to one ankle by a Velcro strap. The examiner held the ends of the resistance band one meter away from the participant's extended foot. The participant was then instructed to bend his knee to 90° against the resistance from the band, and then extend his knee back to full extension. Repetitions were performed to a cadence of 80 beats per minute; the participant flexed his knee on one beat and extended his knee on the next. The test was terminated if the participant was no longer able to bend his knee to 90°, or keep up with the cadence. The resistance band was replaced every 100 repetitions to ensure that the resistance provided by the band was consistent for all participants. This test was created by the researchers. Our intent was to pilot the test for feasibility in this study and we have not yet performed analyses for validity and reliability. The movement mimics an exercise commonly performed on an exercise machine (a leg/knee extension) which is intended to improve muscular fitness of the hamstrings (Baechele & Earle, 2000).

[Insert Figure 2]

Upper Back Strength Test. This test measures isometric strength of the upper back muscles with a portable Baseline Back-Leg-Chest Dynamometer (AliMed, Inc.Dedham, MA). Participants began by standing on the foot platform of the dynamometer, holding onto a handle and pull chain which was attached to the platform. They were then instructed to bend their knees and elbows to 45° and maintain an upright torso. Subsequently, the examiner adjusted the length of the pull chain so that the handle rested in the crease between the participant's legs and torso. An illustration of a person performing the test was provided so the participants could visualize the correct posture. Once the participants had assumed the correct position they were instructed to pull the handle upward and backward simultaneously by squeezing their shoulder blades together and using maximal effort. If the participant extended his knees, that trial was not counted and he tried again. The examiner recorded the isometric force produced on the dynamometer (to the nearest Kg) as an average of three successfully executed trials. This test is validated against back extension force during an upright pull using an electronic dynamometer ($r=.75$) (Kroll, Machado, Happy, Leong, & Chen, 2000) and was utilized in a study in which an aggregate fitness score was associated with back injury incidence in firefighters (Cady et al., 1979). There is no reliability information available for this test.

Upper Back Endurance Test (bent-over-row). This test assesses muscular fitness of the upper back. Participants were instructed to stand with flexed knees and their torso bent to a 45° angle while holding a 20-pound hand weight in each hand. To begin the test participants were asked to flex their elbows and bring the weights up to the level of their chest. The repetition was completed as the participants extended their elbows to bring the weights back down. The repetitions were performed to a cadence of 80 beats per minute; participants brought the weights up on one beat and lowered the weights back down on the next beat. The test was

terminated if the participant was unable to maintain a neutral spine, bring the weights up to chest level or complete the repetitions at the required cadence. This movement is an exercise commonly performed to improve muscular fitness of the upper back (Baechle & Earle, 2000) and performance on this test has been correlated with firefighter job performance ($r=-0.61$) (Rhea et al., 2004). However, there are no laboratory based validity information nor estimates of reliability for this test.

Statistical Analysis

All data were analyzed using Stata (Statacorp LP; College Station, Texas). A zero-inflated Poisson regression analysis was used to investigate the relationship between scores on the back fitness tests and firefighters' history of back injuries. The trunk rotation test was not included in the regression because scores were not normally distributed and we were not able to achieve normality with a transformation. Number of years on the job was included to account for exposure time. Odds ratios for a change in the expected number of injuries were calculated for a one unit change (for example: one Kg on the upper back strength test) as well as a one standard deviation change in scores on the back fitness tests.

Power analysis

Computing power in a Poisson regression requires estimation of baseline response rate (the expected rate of back injuries when each predictor equals the mean) and exposure time (the mean unit of time over which the back injuries occurred) in addition to setting a significance level α (Faul, Erdfelder, Buchner, & Lang, 2009). The baseline response rate was expected to be .5 because 50% of the firefighters reported having experienced a back injury. The exposure time was 14 years since that was the average number of years on the job in the sample. The

significance level α was set at 0.05. Since 113 firefighters participated in this study, a 15% increase in the rate of back injuries with every one unit increase in the predictor variables can be detected with a power of 0.95.

RESULTS

The mean age of the firefighters was 37.7 ± 8.8 and ranged between 24 and 64 years. The average number of years as a paid firefighter was 11.8 ± 8.5 and ranged between .5 and 33. Descriptive statistics for the firefighters and the back fitness tests are shown in Table 1. Over half (51%) of the firefighters reported experiencing at least one back injury on-duty sometime throughout their careers. Of those firefighters, 24 (21%) reported experiencing only 1 back injury in their careers, 14 (12%) reported experiencing 2 back injuries and 20 (18%) reported experienced 3 or more back injuries (Figure 3). Increasing age was associated with lower scores on the lumbar flexion and extension tests; age was not associated with any of the other back fitness tests.

[Insert Table 1]

[Insert Figure 3]

Changes in the expected number of back injuries are shown in Table 2. Number of back injuries was significantly related to lumbar extension ($p < 0.01$) only. For every one centimeter increase in lumbar extension scores, indicating a greater degree of lumbar extension flexibility, the expected number of back injuries during a career increased by 52.1% ($p < 0.01$). To better understand these results we created six groups according to lumbar extension scores and entered these into a Poisson regression to calculate the rate of back injury for each group

adjusting for years on the job. Figure 4 shows an apparent dose-response relationship; the rate of back injury increased as lumbar extension scores increased. However, the trend is not significant.

[Insert Table 2]

[Insert Figure 4]

DISCUSSION

We aimed to investigate whether firefighters' history of back injury was related to their scores on tests of back strength and endurance, hamstring strength and spine flexibility. We found that the number of injuries experienced by firefighters was related to spine flexibility in extension. We also hypothesized that back strength and endurance assessments would provide the best indication of back injury risk in firefighters. We found that our tests of back strength and endurance were not associated with back injury incidence among our sample of firefighters.

Given that a host of performance studies present data indicating that upper body strength and endurance are most important when performing firefighting tasks, and lifting is the primary activity responsible for back injuries outside of fire suppression, we posited that understanding one's upper back fitness may be promising in terms of estimating back injury risk. Although Rhea (Rhea et al., 2004) found that the bent-over-row test assessing back muscle endurance was associated with job performance, it had never been considered as a screening test for injury. Also, a static upper back strength test using dynamometry was included in Cady's landmark study (Cady et al., 1979) but it also had never been considered as a screening test for injury. While our results do not indicate that these tests predict the likelihood of a back injury, the work of other authors suggests that it would be advantageous for firefighters to perform

exercises such as the bent-over-row in that ample upper body/upper back strength is associated with enhanced job performance.

These results do not follow conventional wisdom regarding the effect of high muscular strength and endurance toward protection from injury. The same is true of our findings that *less* back extension capability is associated with lower back injury risk. Traditionally, improving back flexibility is promoted as an injury reduction strategy in firefighters. As discussed earlier, Hilyer and colleagues (Hilyer et al., 1990) reported that firefighters developed better flexibility of the trunk, shoulders and knees and experienced fewer lost work days after participating in a 6-month stretching program, although the proportion of total injuries that affected the back was not reported. In addition, Cady et al (Cady et al., 1985) claimed that Los Angeles firefighters who exhibited the highest back flexibility scores incurred much lower medical costs due to back injuries compared to those with the lowest back flexibility scores. However, in both studies back flexibility was assessed by the sit-and-reach test while we used a more direct measure of lumbar spine flexibility. In fact, research shows that scores on the sit-and-reach test are determined to a greater degree by hip flexibility ($R^2=.42$) than by lumbar flexibility ($R^2=.3$) (Chillón et al., 2010). Since greater range of motion at the hip may improve one's ability to maintain a neutral spine during lifting, perhaps it is adequate flexibility of the hips/hamstrings, rather than the spine, that contributes to a lower back injury risk for firefighters.

The relationships between flexibility and injury have been studied in the general population and occupational workers and the results of these studies do not elucidate a clear pattern between spine flexibility and injury risk (Hess & Hecker, 2003). Grenier showed that industrial workers who had suffered from disabling back problems ($n=26$) exhibited less lumbar flexion and extension range of motion compared to workers with no history of back disorders ($n=24$) (Grenier, Russell, & McGill, 2003). Yet other authors reported that for 449 working men

between the ages of 30 and 60, those with higher levels of spine flexibility were more likely to develop back problems over the ensuing year (Biering-Sorensen, 1984). Perhaps for firefighters, less range of motion in the low back affords greater stability and a heightened ability to maintain a neutral spine during physically demanding tasks. Although more research is needed to confirm that hypermobility in spinal extension is a risk factor for back injury in firefighters, the most significant finding of our research is that heightened spinal extension is associated with a greater rate of back injury among firefighters. These findings can be applied by employing the Modified-Modified Schober test, which is very simple to perform, and counseling those who possess greater flexibility on improving their core musculature to heighten stability.

Unfortunately we do not know whether spinal flexibility in rotation is related to injury risk in firefighters because for our assessment there appeared to be a ceiling effect; a large proportion of the participants rotated as far as the trunk rotation tool would measure. So scores on this variable were not normally distributed and we were not able to transform the scores to achieve normality. We still believe that trunk rotation flexibility may relate to injury risk for two reasons: First, a trunk rotation test was included in the testing protocol in the studies conducted by both Hilyer (Hilyer et al., 1990) and Cady (Cady et al., 1985), in which an overall reduced injury incidence was associated with improved/adequate flexibility although neither reported the methods or tools used to conduct the test. Second, there are many firefighter tasks that require twisting of the spine including maneuvering a stretcher down a staircase, pulling an individual out of a car or swinging an ax. In the future, trunk rotation should be assessed using a method that does not have a maximum measurement.

We also postulated that hamstring strength would be more likely to relate to injury risk compared to quadriceps strength which is measured primarily in a squat or leg press test. The hamstrings are hip extensors in conjunction with the gluteal muscles and thus are recruited

when lifting something anterior to the trunk, an activity that is frequently encountered by firefighters as they must transfer patients from a bed, for example, onto a gurney, and then lift and carry the gurney out of the house and into the ambulance. Firefighters with poor hip extension strength may be more likely to bend over and flex the spine during lifting tasks, increasing the compression force that leads to a herniated intervertebral disc (Neumann, 2010). Lavender has shown that when leaning forward to lift a patient from a bed to a gurney, the compression force at the fourth and fifth lumbar vertebrae exceeds 5,000 Newtons (N) (Lavender, Conrad, Reichelt, Meyer, et al., 2000). While research has shown that the healthy young male spine can tolerate between 12,000 and 19,000 N of compression force in one load, this threshold likely lowers as a firefighter repetitively performs this lifting task. In vitro, herniation of the intervertebral disc has been observed when the spine is loaded with only 1,472 N and a flexion motion (like that performed when lifting a gurney) is repeated between 5,000 and 9,500 times (McGill, 2002). Thus it is likely the magnitude of forces produced by firefighting tasks such as patient transfer are sufficient to cause damage to the spine, especially over time, and that possessing adequate strength in the posterior leg and trunk muscles attenuates the forces imposed on the spine. However, scores on our test of hamstring strength did not relate to injury incidence. In retrospect, a better method of assessment would be to actually mimic the act of lifting something anterior to the trunk to recruit the gluteal and low back muscles in addition to the hamstrings.

Yet the foremost limitation of our study is that it is cross-sectional and retrospective rather than prospective. It is possible that a firefighter may have performed well on the fitness tests only because he or she had experienced a back injury in the past and made the effort to become more fit to avoid future injury. We believe it more likely, however, that deficits in these aspects of fitness may have contributed to back injuries and that these deficits would still be

lingering for the majority of the injured firefighters and perhaps even exacerbated as a result of disuse. McGill demonstrated that deficits in fitness were evident for a group of workers (n=26) who had a history of back injuries (but who were asymptomatic at the time) compared to workers (n=48) with no history of back problems (McGill et al., 2003). We intend to follow the firefighters that participated in our study to determine if their fitness scores predict injury occurrence in the future.

This study has several strengths. First, our protocol was novel as we used only field-based assessments, rather than clinical or laboratory-based tests which require the use of expensive equipment or laboratory facilities. Our intent was to develop inexpensive, simple tests that fire departments can utilize to screen their personnel for back injury risk and point to areas that warrant improvement. Another strength of this study relates to how the tests were administered. Firefighters were in their natural work environment when they participated in the fitness tests because they were on duty at the time. While scores on the fitness tests were kept private by the researchers, the firefighters' peers were still within the general vicinity during the testing period and that likely influenced the effort they put into the tests. This mimics the firefighters' work environment; they constantly perform work related physical tasks together with their peers.

However, conducting the testing on duty also presented a limitation: we were time constrained as we had to keep the firefighters' time away from their regular duties to a minimum. So we were only able to choose three tests related to back strength/endurance, two tests for lumbar flexibility (only one of which provided suitable results for inclusion in the analysis) and one test for hamstring strength. It is very possible that we did not choose the best tests to assess these components of fitness. Thus, our results should not be interpreted to mean that hamstring strength or upper back endurance, for example, are not related to injury risk in

firefighters, but rather that scores on the specific tests that we utilized are not related to back injury.

Possessing limited lumbar extension flexibility, as measured using the *Modified-Modified Schober test*, is associated with a lower risk for back injuries among firefighters. However, a prospective study is needed to confirm that this aspect of fitness predicts the occurrence of back injuries for firefighters in the long term. Furthermore, there are other factors aside from fitness that may play a role in back injury risk such as firefighters' knowledge and implementation of proper lifting mechanics, psychosocial factors such as perceived peer pressure to fulfill job responsibilities, or firefighters' perceptions of their fitness related to their physical ability to carry out difficult job tasks, and whether equipment is designed in the most ergonomic fashion. Future research should take a holistic approach to investigating how fitness along with these other factors can mitigate back injury risk for firefighters.



Figure 1: Trunk Rotation test. Participants sat in a chair with a Velcro strap wrapped around their chest, with a dowel protruding from the sternum. Their arms rested over a dowel placed across the shoulders. The trunk rotation measurer was placed in front of each participant. They then rotated as far as possible to each side while the researcher measured the distance traveled by the chest dowel to the nearest degree.



Figure 2: Hamstring Strength test. Participants sat on the edge of the bench with a resistance band secured to one ankle by a Velcro strap. The examiner held the ends of the resistance band one meter away from the participant's extended foot. The participant was then instructed to bend his knee to 90° against the resistance from the band, and then extend his knee back to full extension. Repetitions were performed to a cadence of 80 beats per minute; the participant flexed his knee on one beat and extended his knee on the next. The test was terminated if the participant was no longer able to bend his knee to 90°, or keep up with the cadence.

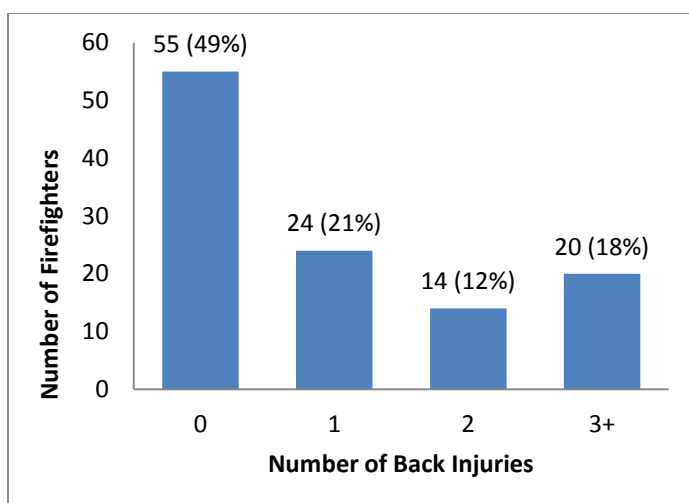


Figure 3: Proportion of firefighters reporting back injuries (N=113). Firefighters reported whether they had experienced 0, 1, 2 or 3+ back injuries throughout their careers.

Table 1

Descriptive Statistics for Firefighters and Back Fitness Tests

Parameter	Mean	SD	Range
Age	37.7	8.8	24-64
Years as a paid FF*	11.8	8.5	0.5-33
Chin Up (cm)	35.4	7.5	14-54
Lumbar Flexion (cm)	21.4	1.3	18-24.5
Lumbar Extension (cm)	2.3	1.1	0.25-5
Hamstring Strength (repetitions)	52.0	27.7	5-200
Back Strength (kg)	115.2	25.9	70-200
Back Endurance (repetitions)	49.8	16.9	20-100

*FF = firefighter

Table 2

Percentage Change in Expected Number of Back Injuries

Test	coefficient	<i>p</i> -value	% change by 1	% change by <i>SD</i>	<i>SD</i>
Chin Up (cm)	0.00	NS*	0.4	3.1	7.52
Lumbar Flexion (cm)	0.10	NS	10.9	14.2	1.23
Lumbar Extension (cm)	0.42	0.003	52.1	55.1	1.05
Hamstring Strength (repetitions)	0.00	NS	7.7	7.7	27.73
Back Strength (kg)	0.00	NS	4.5	4.5	24.45
Back Endurance (repetitions)	0.01	NS	9	9	16.95

*NS = not significant at .05

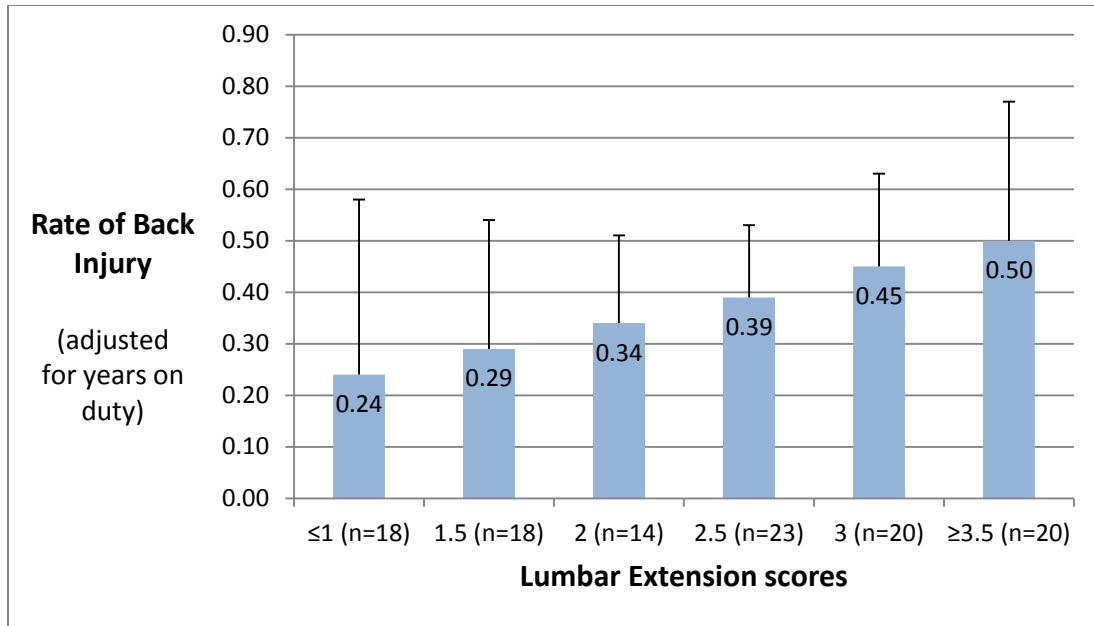


Figure 4: Rate of back injury by lumbar extension scores. Among this sample of 113 firefighters, the rate of back injury increased as lumbar extension scores increased. However, the observed increase is not statistically significant.

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CHAPTER THREE

INVESTIGATING PERCEIVED FITNESS IN FIREFIGHTERS: RELATIONSHIPS WITH ACTUAL FITNESS AND INCIDENCE OF BACK INJURY

Submitting to *Work: A Journal of Prevention, Assessment & Rehabilitation*

ABSTRACT

Near half of all firefighters have at least one back injury during their career and many sustain multiple back injuries. The factors contributing to the high incidence of back injuries in firefighters are understudied. While fitness has traditionally been considered the most important factor affecting injury risk in firefighters, there are also psychological factors that have not been explored. If firefighters' perceptions of their fitness are not aligned with their actual physical abilities they may enter into more hazardous situations or perform tasks in an unsafe manner that increases injury risk. **Purpose:** To examine the relationships between firefighters' perceptions of their fitness, their actual fitness and their history of back injuries. **Methods:** Firefighters from three fire departments (n=160) completed surveys regarding their history of back injuries and their perceptions of their fitness. A subgroup of 113 firefighters also participated in eight back-fitness tests: A *Modified-Modified Schober test* for lumbar flexion and lumbar extension, a trunk rotation flexibility test, a back endurance "row" test, a back strength test, a hamstring strength test and a prone chin-up test. A zero-inflated Poisson (ZIP) regression analysis was used to investigate the relationships between scores on the back fitness tests, scores on the PSPP, interactions between PSPP and fitness test scores, and history of back injury. Number of years on the job was included to account for exposure time. A Pearson correlation was used to investigate whether scores on the PSPP were related to scores on the

back fitness tests. **Results:** The firefighters' mean age and years on the job were 38.8 ± 8.9 and 13.0 ± 8.5 , respectively. Sixty-nine of the total sample (43%) reported never experiencing a back injury at work, 33 (21%) reported one back injury, 24 (15%) reported two back injuries and 34 (21%) reported three or more back injuries. In ZIP regression, only the Lumbar Extension test was associated with number of back injuries ($p < 0.01$). Possible scores on the PSPP ranged from 1 (lowest perceived fitness) to 4 (highest perceived fitness). Among this sample the mean scores on the Strength and Condition subscales were 2.94 ± 0.45 and 2.85 ± 0.60 , respectively. Scores on the PSPP were not significant predictors of back injuries and there were no significant interactions between PSPP scores and scores on the back fitness tests ($p > 0.05$). Significant correlations existed between scores on the PSPP and the Back Strength test ($r = 0.28$; $p = 0.003$) and the Hamstring Strength test ($r = 0.21$; $p = 0.03$). **Conclusion:** Fitness alone may not be a strong predictor of injury risk in firefighters as all but one of the fitness tests in our study were unrelated to back injuries. Asking firefighters how fit they believe themselves to be may also not be a viable strategy for predicting their risk for back injury. The next step is to understand how firefighters' perceptions of their fitness ultimately direct their behavior when performing work tasks.

Key Words: firefighters, back injuries, perceived fitness

INTRODUCTION

Firefighting is a very physically strenuous occupation. According to the United States Bureau of Labor Statistics, the rate of injury related absenteeism in the fire service is higher than any other profession and firefighters are three times more likely to be injured than workers in the manufacturing, agricultural and construction trades (U.S. Bureau of Labor Statistics, 2011).

Although it is clear that the physical nature of firefighting is the main contributor to such a high injury incidence (Karter, 2012), there are many factors other than the firefighters' physical fitness that play a role in their risk for injury. For example, postural mechanics during strenuous tasks affects how hazardous those tasks are to the body (Gentzler & Stader, 2010; Lavender, Conrad, Reichelt, Meyer, & Johnson, 2000). Research has demonstrated that if firefighters do not maintain an upright torso and neutral spine when lifting patients, the load imposed on the spine exceeds the threshold for injury (Lavender et al., 2000), and back injuries are the most commonly occurring type of injury to firefighters (International Association of Firefighters, 2000). Additional ergonomic considerations relate to equipment usage; resulting in the development of more favorable ergonomic designs for equipment used during firefighting and emergency aid (Conrad, Reichelt, Lavender, Gacki-Smith, & Hattle, 2008; Gentzler & Stader, 2010). Another potential contributing factor that has received less attention in the literature is firefighters' work-related physical behaviors. Research has illustrated that peoples' behaviors are driven by their outcome expectations related to participating in a particular task (Bartlett, Li, & Zhang, 2007). As such, it is plausible that injury risk is determined not only by firefighter's physical abilities to perform tasks but also by their beliefs regarding their ability to perform a task without becoming injured.

While there are no data to discern how firefighters' perceptions of their fitness relate to injury risk, research has shown that firefighters do indeed believe their fitness level, among other factors, affects their susceptibility to injury on the job (Reichelt & Conrad, 1995). It seems possible that those who believe they are stronger and better conditioned than their peers are more likely to enter physically strenuous situations on-duty which may put them at greater risk for injury. For example, those who feel they are more physically capable than their crew

members may choose the most physically demanding position when lifting a gurney, a task which puts firefighters at increased risk for straining their backs (Lavender et al., 2000).

The notion that people who believe they are strong may choose lifting strategies that are more risky in terms of injury was illustrated in a study in which 32 men and women were asked to complete a task that required moving a stack of weights from one location to another (Bartlett et al., 2007). First they were measured on four isokinetic strength tests but were not informed of their strength levels prior to completing the task. Generally, individuals who scored well on the strength tests chose to carry more weight per lift than did weaker individuals even though participants were instructed to take as much time as needed to complete the task. Yet, if the environmental conditions encourage or require strength (as in the firefighting profession) it is possible that those who lack strength may still perceive that they are sufficiently strong and may choose the riskier lifting strategy.

While perceived fitness was not measured in the aforementioned study, a handful of researchers have examined firefighters' perceptions of their fitness in comparison to actual fitness (Peate, Lundergan, & Johnson, 2002; Saborit et al., 2010). Results from both of these studies suggest that perceived fitness and actual fitness do not align among the firefighters studied. For instance, in a group of 37 firefighters who completed a perceived fitness survey and performed a graded exercise test, almost all of the firefighters with an aerobic capacity lower than that deemed sufficient for firefighting (42 ml/Kg/min) reported that they thought they had "high" or "very high" cardiovascular endurance (Saborit et al., 2010). In a similar study, Peate and colleagues found a lack of association between firefighters' measured aerobic capacity and self-reported physical fitness level (Peate et al., 2002). Whether disparities in actual and perceived fitness exist in the strength domain among firefighters is unknown.

In addition, the limitations of these studies support the need for further investigation as neither study utilized a validated tool to assess firefighters' perceptions of their fitness. In fact, Peate et al. used a questionnaire that required firefighters to rank their fitness level on a scale from 0 to 7; "I avoid walking or exertion..." was the response associated with a ranking of 0 and "I run over 10 miles per week..." was the response associated with a ranking of 7. While these authors reported that they measured firefighters' perceptions of their fitness level, they actually measured firefighters' perceptions of their activity level. Furthermore, neither study assessed firefighters' perceptions of their muscular strength, and this component of fitness is likely more closely related to injury than is aerobic capacity (McGill, 1997). To our knowledge, no information is available regarding the relationships between firefighters' perceptions of their muscular strength and overall physical conditioning and their history of injuries. Yet, this information could help us understand if firefighters' injury risk is affected by how fit they believe themselves to be, and whether these beliefs influence the relationships between fitness and risk for back injury, which could ultimately inform the development of an intervention to lower incidence of back injuries in firefighters. Thus, the purpose of this study was to examine the relationships between firefighters' perceptions of their fitness, their actual fitness and their history of back injuries.

METHODS

Design

This was a cross-sectional study conducted at fire stations in each of three urban fire departments in Oregon. Approximately 250 career firefighters were invited to participate. This study was approved by the Oregon State University Institutional Review Board and all participants gave written informed consent prior to participation.

Procedures

A total of 160 male firefighters between the ages of 24 and 64 completed surveys about their history of injury on the job and their perception of their fitness compared to other firefighters. A sub-sample of 113 male firefighters who completed the surveys underwent six short fitness assessments while on-duty. Firefighters who reported suffering from neck, back or leg injuries on the injury survey (n=19) were excluded from the fitness testing portion of the study.

History of Injury Survey: The history of injury survey was an 11-item questionnaire developed to gather information about the number and type of injuries experienced by firefighters participating in the study. Specifically, firefighters were asked to report if they had suffered from 0, 1, 2 or 3+ back injuries throughout their careers. They were also asked to report the nature and cause of their back injuries and their age and number of years on the job. The criteria for determining whether a firefighter had experienced an injury was a “yes” response on the following survey question: “Assume that a ‘back injury’ describes something that happened **at work only** and that resulted in moderate to severe pain in your back for a prolonged period of time. These may or may not be injuries that caused you to miss work days. In that sense, have you ever experienced a back injury while on duty as a firefighter?” This was a self-report measure and was not validated against injury records as they were not made available to us by the fire departments. The use of a self-report measure ensured that all injurious events were accounted for, even for those firefighters who did not choose to file a workers compensation claim as a result.

Perception of Fitness: Perceived fitness was measured using the “strength” and “condition” subscales of the Physical Self Perception Profile (Fox & Corbin, 1989). This

instrument was designed to assess perception of fitness as it compares to others of the same gender and in this case, the same occupation. We selected these subscales because we hypothesized that a firefighter's strength and overall physical condition may be related to back injury risk. The Strength and Condition subscales consist of 6 questions each. The Strength subscale asks questions specific to how the person feels about his strength while the Condition subscale asks questions about how the person feels about his overall physical condition. Possible scores range from 1 (lowest perceived fitness) to 4 (highest perceived fitness). The questions were adapted specifically for this population by replacing "other people" with "other firefighters" within the text of each question.

To answer each question, the participant first decides which of two types of people (firefighters) are most like him. Next, he chooses if that statement is "sort of true" for him or "really true" for him. As an example, one question on the Condition subscale begins with: "Some firefighters do not usually have a high level of stamina and fitness BUT others always maintain a high level of stamina and fitness." He first decides whether he is more like those who do not maintain a high level of fitness or if he is more like those who do maintain a high level of fitness. Once he has determined which side of the statement best describes him, he responds as to whether that is "really true" or "sort of true" for him. The questions appear in the instrument as follows:

	Really True For Me	Sort of True For Me			Sort of True For Me	Really True For Me
1.	[]	[]	Some firefighters do not usually have a high level of stamina and fitness	BUT	Others always maintain a high level of stamina and fitness.	[] []

To give another example, a question on the Strength subscale begins with: "Some firefighters feel that their muscles are much stronger than most others of their sex BUT others

feel that on the whole their muscles are not quite so strong as most others of their sex.” The firefighter goes on to report whether the side of the statement that describes him best is “really true” or only “sort of true” for him. The reliabilities of the subscales (α) have been shown to be between 0.80-0.95. Test-retest reliability has been shown to be between 0.74-0.89 (Fox & Corbin, 1989). The Firefighter Perception of Fitness and History of Back Injury Survey is shown in Appendix C of this dissertation.

Fitness Assessment Test Battery: Firefighters performed a 5-minute warm-up that consisted of walking outside or on a treadmill, and then completed the following fitness tests organized as a circuit:

Chin-up Test. This test assesses back flexibility in extension. Participants were required to lie face down on a mat, with hands resting by their sides. Without using their hands, participants were asked to slowly arch their back so their head and chest rose off the ground while looking forward and keeping their chin level. The distance that participants raised their chin off the floor was measured using a yardstick and recorded to the nearest quarter of a centimeter. This test is part of the YMCA FITNESSGRAM protocol and has been validated against goniometer measurements of trunk flexibility ($r=.7$). Reliability is .9 for a single trial test (Patterson, Rethwisch, & Wiksten, 1997).

Trunk Rotation Test. This test measures spine flexibility in axial rotation. Participants sat in a chair with a Velcro strap wrapped around their chest, with a dowel protruding from the sternum. Their arms rested over a dowel placed across the shoulders. The trunk rotation measurer, which resembled a table with a semicircle cut out of it, was placed in front of each participant. They then rotated as far as possible to each side while the researcher measured the distance traveled by the chest dowel to the nearest degree. We constructed the trunk rotation assessment tool based on specifications reported in another study that used the instrument to

collect data for the purposes of relating fitness with back injury incidence in firefighters (Cady, Bischoff, O'Connell, Thomas, & Allan, 1979). There are no estimates of validity and reliability for this test.

Lumbar Flexibility Test (Modified-Modified Schober test). This test measures flexibility of the lumbar spine in flexion and extension. The examiner first marks the participants back at the base of the lumbar spine and 15 cm above the first mark using a cloth measuring tape. To assess spinal flexion, participants began from a standing position with shoulders aligned over the hips. They were instructed to bend forward at the waist as far as possible allowing their lumbar spine to flex. The new distance created between these two marks was measured and recorded to the nearest quarter of a centimeter. Greater range of motion in spinal flexion is indicated by larger values. To assess spinal extension, participants began from upright standing with shoulders and hips aligned, and were instructed to bend backward at the waist while allowing the pelvis to move anteriorly. Increasing range of motion in spinal extension resulted in the marks becoming closer to one another. Therefore, the new distance between the two marks was subtracted from 15 cm so that larger values indicated greater spinal extension flexibility. This test has been validated against x-ray measurements of lumbar spine flexibility ($r=.67$) and intra-tester reliability is 0.95 (Tousignant, Poulin, Marchand, Viau, & Place, 2005).

Hamstring Strength Test (Figure 2). This test assesses muscular fitness of the hamstrings. Participants sat on the edge of a bench or chair with a resistance band secured to one ankle by a Velcro strap. The examiner held the ends of the resistance band one meter away from the participant's extended foot. The participant was then instructed to bend his knee to 90°, against the resistance from the band, and then extend his knee back to straight (approximately 180°). Repetitions were performed to a cadence of 80 beats per minute; the participant flexed his knee on one beat and extended his knee on the next. The test was terminated if the participant was

not able to bend his knee to 90°, or keep up with the cadence. The resistance band was replaced every 100 repetitions to ensure that the resistance provided by the band was consistent for all participants. This test was created by the researchers. Our intent was to pilot the test for feasibility in this study and we have not yet performed analyses for validity and reliability. The movement mimics an exercise commonly performed on an exercise machine (a leg/knee extension) which is intended to improve muscular fitness of the hamstrings (Baechle & Earle, 2000).

Upper Back Strength Test. This test measures isometric strength of the upper back muscles with a portable Baseline Back-Leg-Chest Dynamometer (AliMed, Inc. Dedham, MA). Participants began by standing on the foot platform of the dynamometer, holding onto a handle and pull chain which was attached to the platform. They were then instructed to bend their knees and elbows to 45° and maintain an upright torso. . Subsequently, the examiner adjusted the length of the pull chain so that the handle rested in the crease between participants' legs and torso. An illustration of a person performing the test was provided so the participants could visualize the correct posture. Once the participants had assumed the correct position they were instructed to pull the handle upward and backward simultaneously by squeezing their shoulder blades together and using maximal effort. If the participant extended his knees, that trial was not counted and he tried again. The examiner recorded the isometric force produced on the dynamometer (to the nearest Kg) as an average of three successfully executed trials. This test is validated against back extension force during an upright pull using an electronic dynamometer ($r=.75$) (Kroll, Machado, Happy, Leong, & Chen, 2000) and was utilized in a study in which an aggregate fitness score was associated with back injury incidence in firefighters (Cady et al., 1979). There is no reliability information available for this test.

Upper Back Endurance Test (bent-over-row). This test assesses muscular fitness of the upper back. Participants were instructed to stand with flexed knees and their torso bent to a 45° angle while holding a 20 lb hand weight in each hand. To begin the test participants were asked to flex their elbows and bring the weights up to the level of their chest. The repetition was completed as the participants extended their elbows to bring the weights back down. The repetitions were performed to a cadence of 80 beats per minute; participants brought the weights up on one beat and lowered the weights back down on the next beat. The test was terminated if the participant was unable to maintain a neutral spine, bring the weights up to chest level or complete the repetitions at the required cadence. This movement is an exercise commonly performed to improve muscular fitness of the upper back (Baechle & Earle, 2000) and performance on this test has been correlated with firefighter job performance ($r=-0.61$) (Rhea, Alvar, & Gray, 2004). However, there are no laboratory based validity information nor estimates of reliability for this test.

Statistical Analysis

All data were analyzed using Stata (Statacorp LP; College Station, Texas). A zero-inflated Poisson (ZIP) regression analysis was used to investigate the relationships between scores on the back fitness tests and scores on the PSPP and history of back injury. The two subscales of the PSPP were analyzed separately. The trunk rotation test was not included in the regression because a large proportion of the participants rotated as far as the trunk rotation tool would measure, so scores were not normally distributed and we were not able to achieve normality with a transformation. Number of years on the job was included to account for exposure time. A test of interaction between fitness scores and PSPP scores was utilized to investigate whether the effect of actual fitness on history of back injury was mediated by perceived fitness.

Likelihood ratio tests were used to compare fit between the model with only back fitness tests and models including PSPP scores and interactions. Odds ratios for rate of injury were calculated for a one-unit change as well as a one-standard deviation change in scores on the back fitness tests and the PSPP. Finally, a Pearson correlation was used to investigate whether scores on the PSPP were related to scores on the back fitness tests.

Power analysis

Computing power in a Poisson regression requires estimation of baseline response rate (the expected rate of back injuries when each predictor equals the mean) and exposure time (the mean unit of time over which the back injuries occurred) in addition to setting a significance level α (Faul, Erdfelder, Buchner, & Lang, 2009). The baseline response rate was expected to be .5 because 50% of the firefighters reported having experienced a back injury. The exposure time was 14 years since that was the average number of years on the job in the sample. The significance level α was set at 0.05. Since 160 firefighters participated in this study, a 10% increase in the rate of back injuries with every one unit increase in PSPP scores can be detected with a power of 0.95.

RESULTS

Descriptive data are presented in Table 1. The mean age of the firefighters who completed both the back injury survey and the fitness tests ($N=160$), was 38.8 ± 8.9 years and ranged between 24 and 64 years. The average number of years on the job was 13.0 ± 8.5 and ranged between 0.5 and 33 years. Sixty-nine of the total sample (43%) reported never experiencing a back injury at work, 33 (21%) reported one back injury, 24 (15%) reported two back injuries and 34 (21%) reported three or more back injuries (Figure 1).

[Insert Figure 1]

For the PSPP, each question is scored from 1 to 4; 1 representing the lowest perceived fitness and 4 representing the highest. Each subscale consisted of 6 questions; firefighters' responses on the 6 questions were averaged to obtain one score (between 1 and 4) for the Strength subscale and one for the Condition subscale. The mean score on the Strength and Condition subscales were 2.94 ± 0.45 and 2.85 ± 0.60 , respectively. In simple linear regression age was not related to PSPP scores. In ZIP regression scores on the PSPP did not predict number of back injuries.

For the subgroup of 113 firefighters who participated in the back fitness tests, age, years on the job, incidence of back injury and scores on the Strength subscale of the PSPP were not significantly different from the 47 firefighters who did not participate in the fitness tests (Table 1). However, scores on the Condition subscale of the PSPP were significantly higher for the firefighters who participated in the back fitness tests compared to the firefighters who did not ($p=0.01$). For the subgroup, the mean age was 37.7 ± 8.8 and ranged between 24 and 64 years. The average number of years on the job was 11.8 ± 8.5 and ranged between 0.5 and 33. Over half of these firefighters reported experiencing at least one back injury sometime throughout their careers. Of those, 24 (21%) reported one back injury, 14 (12%) reported two back injuries and 20 (18%) reported three or more back injuries. The mean scores on the Strength and Condition subscales of the PSPP were 2.97 ± 0.47 and 2.95 ± 0.60 , respectively.

[Insert Table 1]

In ZIP regression, a one-centimeter increase in Lumbar Extension scores was associated with a 52.1% increase in the expected number of back injuries ($p=0.003$). Scores on the PSPP were not significant predictors of back injuries. There were no significant interactions between PSPP scores and scores on the back fitness tests. Likelihood ratio tests confirmed that the model with only back fitness tests and history of injury was preferred over the models including PSPP scores and interactions ($p>0.05$).

Significant correlations existed between scores on the Strength subscale of the PSPP and the Back Strength test ($r=0.28$; $p=0.003$) and the Hamstring Strength test ($r=0.21$; $p=0.03$) but not with the Back Endurance, Lumbar Flexibility or Chin Up tests. None of the back fitness tests were correlated with scores on the Condition subscale.

DISCUSSION

We aimed to investigate how firefighters' perceptions of their fitness were related to their actual fitness and their history of back injuries. We found that the number of back injuries experienced by firefighters was not related to firefighters' perceptions of fitness as measured by the PSPP, and that perceived fitness did not mediate the relationships between actual fitness and back injuries. However, the firefighters' responses to questions regarding their perceived strength were modestly correlated with scores on two strength tests (Back Strength, Hamstring Strength) indicating that their perceptions of their strength did align with their measured strength levels.

Our results confirm that the incidence of back injury in the firefighting population is very high but they do not elucidate a clear relationship between perception of fitness and injury risk. To our knowledge, this is the first investigation to assess perceived fitness and its effect on back injury risk among firefighters. This study focused on the relationships between perceived and

measured fitness, and did not assess firefighter behavior. As such, more research is needed to understand how perception of fitness may influence firefighters' *behaviors* when faced with a risky physical task. Research has illustrated that some people change their behavior based on whether they expect that a task will injure them (Yeung, Genaidy, Deddens, & Leung, 2003). Yeung et al. found that when workers performed lifting tasks, the degree to which they felt they could be injured dictated the effort they put into each task (Yeung et al., 2003). Workers were asked to rate the amount of effort they would put forth into 162 different lifting tasks. Seven possible responses ranged from "very low" to "extremely high" effort. The same scale was used to measure the perceived risk of becoming injured during each task. Results revealed that perceived risk of becoming injured during the tasks explained 74% of the variability in effort, and the authors concluded that the workers relied heavily on their perceptions regarding their ability to complete the tasks without injury to determine how they would perform the task. From these findings we could hypothesize that when firefighters perceive they have sufficient fitness to avoid injury during a lifting task, they are more likely to perform the task in a manner that carries greater injury potential. But, unlike in the study by Yeung (Yeung et al., 2003), we did not try to assess how perceived fitness dictates behavior when completing firefighter tasks so we can only theorize that those who believe they are strong, regardless of their actual strength level, may not choose to protect themselves from injury to the best of their ability.

It is also possible that firefighters who choose the most physically demanding position during a lifting task are doing so because they in fact are strong and know themselves to be. In our study, modest but significant correlations existed between perceived strength and actual strength. So the firefighters did appear to have an accurate sense of their strength levels to some degree. This may mean that it is actually the stronger firefighters who are constantly put in the most hazardous situations, accruing stress on the spine which has been shown to lessen

tolerance to physical loading along with the injury threshold (McGill, 1997). Perhaps this phenomenon explains why even very fit firefighters experience back injuries. To test this idea, future investigation into how and why firefighters choose to perform their work tasks is necessary. It is possible the often life threatening situations in which firefighters execute these behaviors may additionally mediate the relationship between perceived fitness, actual fitness, and firefighter behavior.

Although it has been hypothesized that the risk of back injury is lower for strong firefighters, firefighters of all strength levels experience back injuries and indeed, our measures of muscular strength and endurance were not predictive of back injury incidence among this group of firefighters. However, to our surprise we found that back extension capability was positively associated with lower back injury risk. That is, greater range of motion in back extension was associated with a greater number of back injuries. Others have reported that firefighters with greater amounts of “back” flexibility experience fewer injuries (Cady et al., 1979; Hilyer, Brown, Sirles, & Peoples, 1990). However, in neither study did they isolate the lumbar spine in the flexibility assessment, as we did. In fact, both studies employed the sit-and-reach test, which only measures back flexion, and it was in extension that we observed a significant relationship with back injuries. We found no reports in the literature describing a study examining the relationship of back extension range of motion to injury among firefighters, and as such our results should not be seen as contradictory to prior understanding of flexibility and injury risk in this population. The relationship between spinal flexibility and back injuries in the firefighting population clearly needs to be further explored.

One strength of our study is that the tests we used could be easily adopted by fire departments. The equipment needs and expense are minimal and could be administered with a small amount of training. Another strength of this study is its novelty. To our knowledge,

perception of fitness among firefighters has not been measured using a validated scale; nor has the relationship between perceived fitness and back injuries in firefighters been investigated. A limitation of the study is that back injury data was retrospective, so responses on the back injury survey and scores on the fitness assessments may have been influenced by experiencing back injuries and may not accurately represent whether someone is at risk for experiencing future back injuries.

The notion that back injuries are a problem with a multi-faceted cause is not new to the fire service. To illustrate, in 1995 researchers queried 39 firefighters from 14 different departments about their perceptions surrounding on the job injuries. As a whole, the firefighters identified factors relating to physical capacity such as fitness level, fatigue and skill level to be the primary determinants of injury that are unique to each individual. But they also responded that particular to the workplace, working in confined, awkward spaces and interacting with heavy equipment were related to injury risk along with whether the department offered a fitness program (Reichelt & Conrad, 1995). Likely, fire department administrators understand that reducing back injury risk requires intervention on many levels: the ergonomics of on-the-job equipment, job expectations and education, skill level, and firefighters' fitness.

The results of this study add to the body of knowledge regarding back injuries in the fire service. Specifically, we learned that it may be important to assess back extension flexibility and counsel firefighters about proper mechanics, particularly those firefighters with greater range of motion in back extension. We can also reasonably assume that asking firefighters how fit they believe themselves to be does not aid in predicting their risk for back injury. Our findings suggest that a qualitative approach may provide more telling information regarding the relationships between fitness and injury risk. Therefore, the next step in better understanding this complex problem is to *observe* how firefighters' perceptions of their fitness ultimately direct

their choices when faced with risky lifting tasks, and then to decipher whether that information can be used to intervene and reduce the incidence of back injuries in this population.

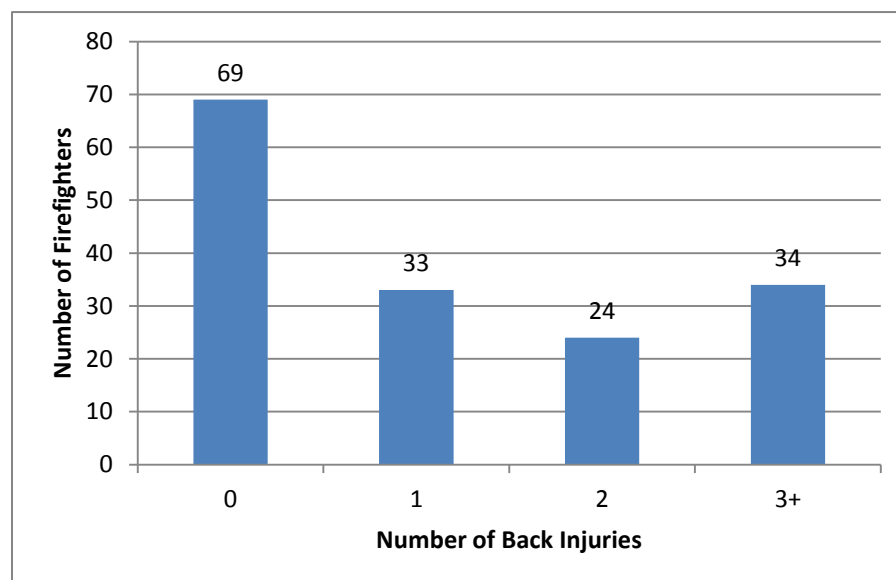


Figure 1: Number of Back Injuries Reported by Firefighters (N=160). Firefighters reported whether they had experienced 0, 1, 2 or 3+ back injuries throughout their careers

Table 1

Descriptive Statistics of Firefighters

<u>All firefighters (N=160)</u>		
<u>Parameter</u>	<u>Mean (SD)</u>	<u>Range</u>
Age	38.8 (8.9)	24-64
Years on the job	13.0 (8.5)	0.5-33
Strength PSPP scores	2.94 (0.45)	1.8-4.0
Condition PSPP scores	2.85 (0.60)	1.5-4.0
 <u>Firefighters Completing the Back Fitness Tests (n=113)</u>		
Age	37.7 (8.8)	24-64
Years on the job	11.8 (8.5)	0.5-33
Strength PSPP scores	2.97 (0.47)	1.8-4.0
Condition PSPP scores	2.95 (0.60)*	1.5-4.0
 <u>Firefighters Not Completing the Back Fitness Tests (n=47)</u>		
Age	41.5 (8.6)	25-60
Years on the job	13.03 (7.8)	2-31
Strength PSPP scores	2.87 (0.39)	2.2-4
Condition PSPP scores	2.61 (0.53)	1.8-4
*significantly higher than firefighters not completing the back fitness tests ($p=0.01$)		

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CHAPTER FOUR

DEVELOPMENT OF A JOB-SPECIFIC SCREENING TEST FOR LOW AEROBIC CAPACITY IN STRUCTURAL FIREFIGHTERS

Submitting to the *Journal of Strength and Conditioning Research*

ABSTRACT

Firefighting requires high fitness to perform job tasks and minimize risk of job-related cardiac death. To reduce this risk, the International Association of Firefighters (IAFF) recommends that firefighters possess a $\text{VO}_2\text{max} \geq 42 \text{ ml/kg/min}$. This recommendation is not universally applied because existing screening tests require costly equipment, and do not accommodate firefighters unable to run. **Purpose:** To develop a walking test using a weighted vest to accurately predict VO_2max in firefighters using a standard treadmill. **Methods:** Thirty-eight male firefighters wore a vest weighing 20% of their body weight and performed a walking VO_2max test on a standard treadmill. Walking speed was determined using the formula: $\text{speed (m/s)} = \sqrt{(0.4 \times 9.8 \times \text{leg length in cm})}$ where 0.4 is a dimensionless Froude number and 9.8 is the acceleration of gravity in m/s^2 . Walking speeds ranged from 3.6 to 4.3 mph. The test began with a 3-minute warm-up following which, speed was increased to test speed. Every minute thereafter the grade increased 1% until participants reached exhaustion. For cross-validation, 13 firefighters also performed a running VO_2max test. **Results:** The average test time was 16.95 ± 2.57 minutes (including warm-up). The range was 8 to 22 minutes; the least fit firefighters finished more quickly. Average VO_2max was $48.4 \pm 6.5 \text{ ml/kg/min}$. Stepwise linear regression included time as the only significant predictor explaining 76% of the variance in VO_2max ($p < 0.001$). The Standard Error of the Estimate was 3.2 ml/kg/min . The equation derived is as follows: VO_2max

(ml/kg/min) = $11.373 + \text{time (min)} * 2.184$. On average, VO_2max values measured while walking were 4.62 ± 5.86 ml/kg/min lower than running values. **Conclusion:** This test has good potential for predicting VO_2max among firefighters, and minimal equipment needs make it feasible for fire departments to administer. Further testing across a broader range of fitness levels is needed to better understand the true utility of this new protocol.

Key Words: firefighters, aerobic capacity, VO_2max test

INTRODUCTION

Firefighting is a very dangerous and physically strenuous occupation evidenced by the 72 on-duty firefighter deaths in 2010 and 61 on-duty deaths in 2011 (Fahy, Leblanc, & Molis, 2011). Heart attacks account for over 50% of these fatalities and for every fatal cardiac event experienced by a firefighter it is estimated that 17 additional non-fatal cardiac events occur among members of the fire service (Soteriades, Smith, Tsismenakis, Baur, & Kales, 2011). Geibe et al. showed that according to autopsy, an on-duty cardiac event is approximately four times more likely to be fatal if a firefighter has established Coronary Heart Disease (CHD), is a current smoker, or is hypertensive (Geibe et al., 2008). However, these authors were not able to include low aerobic fitness in their analysis even though according to the American Heart Association, low aerobic fitness is among the risk factors for developing CHD and experiencing a heart attack (American Heart Association, 2012). In fact, for the general population, some evidence suggests that low aerobic fitness has a stronger influence on CHD-related death than other risk factors (smoking, hypertension, hypercholesterolemia, obesity and diabetes mellitus) (Wei et al., 1999). For firefighters, it has been hypothesized that low aerobic fitness may significantly increase risk for heart attack (Baur, Christophi, Tsismenakis, Cook, & Kales, 2011; Durand et al., 2011; Soteriades et al., 2011). Data illustrates that cardiovascular events are more likely to be

precipitated by strenuous tasks than non-emergency tasks (Kales, Soteriades, Christophi, & Christiani, 2007; Soteriades et al., 2011). For example, during fire suppression the relative risk of heart attack is between 12 and 136 times higher than during non-emergencies (Kales et al., 2007). Several researchers have demonstrated that these job tasks can require high aerobic capacity (Elsner & Kolkhorst, 2008; Holmer & Gavhed, 2007; von Heimburg, Rasmussen, & Medbo, 2006; Williams-Bell, Villar, Sharratt, & Hughson, 2009). During simulated emergency scenarios including walking, crawling, climbing stairs, and pushing, pulling and carrying objects, all while wearing heavy gear, firefighters have exhibited a mean oxygen uptake of 31.54 ± 10.60 ml/kg/min (Elsner & Kolkhorst, 2008), 38.5 ± 5.3 ml/kg/min (Williams-Bell et al., 2009), 43.8 (Holmer & Gavhed, 2007), and 44 ± 5 ml/kg/min (Von Heimburg et al., 2006). Thus it is possible that fitter firefighters experience less physical stress during the unpredictable, intense bouts of exertion that they frequently encounter on the job. In effect, the less fit a firefighter may be, the more strenuous a task becomes relative to their fitness level and the more likely they may be to experience a cardiac event.

Furthermore, evidence supports that for firefighters, possessing high aerobic fitness is associated with better outcomes on other CHD risk factors (Baur et al., 2011; Durand et al., 2011; Geibe et al., 2008). In 968 male firefighters who underwent maximal graded exercise tests (GXT), higher maximal oxygen uptake (VO_2max) was associated with lower resting diastolic blood pressure ($p < 0.01$), total cholesterol/HDL ratio ($p < 0.01$) and fasting blood glucose ($p = 0.03$), and higher HDL-cholesterol ($p < 0.01$), independent of age and Body Mass Index (BMI) (Baur et al., 2011). With the same cohort of firefighters, Durand found that frequent (self-reported) participation in exercise, which was associated with higher aerobic fitness, had similar favorable effects on CHD risk factors and these effects were consistent across all BMI categories (Durand et al., 2011).

In light of the proposed protection from heart attack afforded to firefighters by being aerobically fit, the International Association of Firefighters (IAFF) and the International Association of Fire Chiefs (IAFC) have advocated that all firefighters undergo regular VO_2max testing (administered by qualified exercise professionals) and that they strive to possess a VO_2max of at least 42 ml/kg/min (International Association of Firefighters, 1997). This threshold was identified by reviewing the studies in which oxygen consumption (VO_2) was measured while firefighters participated in simulated emergency scenarios (Elsner & Kolkhorst, 2008; Holmer & Gavhed, 2007; von Heimburg et al., 2006; Williams-Bell et al., 2009). Two investigations revealed VO_2 levels reached 42 ml/kg/min during these tasks (Holmer & Gavhed, 2007; von Heimburg et al., 2006). In order to improve adherence to the recommendation that firefighters undergo regular VO_2max testing, the IAFF has endorsed the “Gerkin” treadmill test. This test is practical because it can be conducted in-house, requires only a standard treadmill, and has an acceptable margin of error associated with the prediction of VO_2max (Standard Error of the Estimate (SEE) = 3.7 ml/kg/min) (Tierney, Lenar, Stanforth, Craig, & Farrar, 2010). While the Gerkin protocol is of tremendous value to the fire service, a major limitation is that it requires running. This is not ideal for two reasons: 1) since the incidence of musculoskeletal injury is very high in the fire service (National Institute of Standards and Technology, 2005), many firefighters cannot run for the length of time required to complete the test without exacerbating symptoms of knee, hip and back pain; 2) firefighters do not run as a function of their duties so the test is not job specific.

Therefore, another test is needed to predict the aerobic capacity of firefighters which does not require running and ideally represents the physical demands of the job. Since firefighters regularly perform job tasks which require walking while wearing protective gear weighing up to 37 Kg (Elsner & Kolkhorst, 2008; Holmer & Gavhed, 2007; von Heimburg et al.,

2006; Williams-Bell et al., 2009), a test which involves walking while wearing heavy gear, such as a weighted vest, would better replicate their day-to-day activity and would be challenging enough for even very fit firefighters. In fact, there are several firefighter job-entry tests (which do not provide the ability to predict VO_2max) that utilize a weighted vest. One such test, used to screen applicants for wildland firefighting, is called the “Pack Test” in which individuals walk a three mile course outside wearing a backpack weighing 20.4 Kg. A weighted vest is also worn during the Candidate Physical Abilities Test, which is a widely used job-entry test that has been validated to simulate the demands of structural firefighting (Sharkey & Davis, 2008). Hence, a VO_2max test with a weighted vest may be ideal in that it is job-specific, requires walking only and would still pose a challenge to even fit firefighters.

Given the high incidence of cardiac events in the fire service and the tight relationship between aerobic fitness and risk for heart attack, it is imperative that screening tests be available to help firefighters understand their risk. However, these assessments must be feasible for fire departments to implement with respect to financial and personnel constraints; they must be able to be conducted in-house, be minimally invasive, and take little time. Another goal is for the test to be job-specific and one that all firefighters can complete. The purpose of this study was to develop a treadmill walking test using a weighted vest, which can be carried out on a standard treadmill, to predict VO_2max in firefighters.

METHODS

Participants

A total of 38 paid and volunteer male firefighters from two departments in Oregon volunteered to participate in the study. To comply with the American College of Sports Medicine (ACSM) criteria for “low risk” while participating in a maximal GXT, all participants were under

the age of 45. Participants were free from chronic disease including asthma and diabetes which would deem them “high risk” and they possessed no more than one risk factor for CHD as determined by the ACSM risk stratification guidelines (Gordon, 2009). Participants were also free from injury to the back or lower extremity which would affect their performance on a GXT. This study was approved by the Oregon State University Institutional Review Board and all participants gave written informed consent prior to participation.

Procedures

Firefighters completed a standard health history questionnaire before the assessment. Height, weight, and resting heart rate and blood pressure were recorded before each test. In order to determine a walking speed for each person that ensured a brisk pace without having to run, we used a Froude number (a dimensionless number that defines a speed/length ratio) which allowed us to standardize each participant’s walking speed by their leg length. First, leg length was measured from the greater trochanter to the lateral malleolus on the participant’s right leg using a cloth measuring tape. Two separate measurements were taken by different researchers. If the two measurements were within two centimeters of one another, they were averaged; if the measurements were not within two centimeters leg length was measured again until they were. Then, we used the principle: Froude number = u^2/gL , where u is traveling speed (m/s), g is the acceleration of gravity (9.8 m/s), and L is leg length (cm) to derive our formula for walking speed. A Froude number of 0.5 corresponds to the speed at which most people transition from walking to running; a higher Froude number indicates a faster pace (Agiouvasitis, Yun, Pavol, McCubbin, & Kim, 2008). Thus, in order to ensure that the participants’ pace did not encourage them to run, we decreased the Froude number to 0.4 in the calculation used to

estimate walking speed. Each participant's measured leg length was entered into the following equation:

$$\text{Speed (m/s)} = \sqrt{0.4 \times 9.8 \times \text{leg length}}$$

The result of this equation was multiplied by 2.236 to obtain mph since our treadmill had units of mph. The calculated walking speeds ranged from 3.6 to 4.3 mph.

Throughout the VO_2max tests, gas exchange was measured and recorded every 15 seconds by a metabolic measuring system (ParvoMedics, Sandy, Utah). The metabolic cart was calibrated using a 3-L syringe and air and gas mixtures of known composition before each testing session (once per day). Heart rate and rhythm were measured by a 12-lead electrocardiogram (ECG; Schiller, Baar, Switzerland). Blood pressure was monitored manually by the researcher during the tests. The criteria to determine whether firefighters reached their VO_2max were either: a) a rise in oxygen consumption of less than 2.0 ml/kg/min after a stage increase, or at least two of the following: b) a Respiratory Exchange Ratio (RER) of 1.15 or higher, c) a heart rate within 10 beats per minute of the participant's age predicted maximum heart rate, d) a Rating of Perceived Exertion (RPE) of ≥ 17 on the Borg RPE scale ranging from 6-20 (Heyward, 1997; Howley, Bassett, & Welch, 1995).

Maximal oxygen uptake was recorded as the highest measured value achieved during the last four 15-second intervals of the test which reflects the procedures by other authors who have developed VO_2max prediction equations (Tierney et al., 2010).

Developing the Walking Protocol

In order to develop the walking treadmill protocol, the research team recruited volunteers and experimented with stage length (1 minute, 2 minutes, etc.), grade increase, and vest weight (as a percentage of body weight) before recruiting study participants. The goal was

to establish a protocol that would allow participants to achieve a steady state heart rate with each stage (to avoid underestimation of VO_2max) but to also ensure that the test would be challenging enough that firefighters across a range of fitness levels would achieve the criteria for reaching their VO_2max .

The following protocol was piloted and ultimately chosen for use in this study by the researchers: before beginning the test, the participants completed a warm-up by walking on the treadmill for 5 minutes and then stretching the hamstrings and back muscles for 5 minutes. After this warm-up, they put on a vest weighing 20% of their body weight. The test began with the participant walking on the treadmill at 3.0 mph at 0% grade for the first 3 minutes. At the end of the third minute the treadmill speed was increased to the pre-determined walking speed that was based on leg length. They walked at this speed at 0% grade for one minute. At the end of the fourth minute, the grade on the treadmill increased to 1% and continued to increase by 1% each minute after that. The participant continued to walk at the pre-determined speed while the grade increased each minute until exhaustion. The protocol proved to be of adequate length; the average time achieved on the test was 16.95 ± 2.57 minutes and ranged between 8 and 22 minutes.

Cross-validation

After participating in the walking test, 13 participants volunteered to participate in a validated running treadmill test to exhaustion. These tests took place between one and four weeks after their walking tests. Before the running tests, participants confirmed that their responses on the health history questionnaire had not changed since their first VO_2max test.

Statistical Analysis

A stepwise linear regression was utilized to create the prediction equation with measured relative VO_2max as the outcome variable and time achieved on the test, height, weight, walking speed, and age as possible predictor variables. For entry into the prediction equation, the time achieved on the test was converted to whole minutes. For example, if a participant achieved a time of 14:30, then 14.5 minutes was used in the analysis.

For cross-validation, a Bland-Altman plot was used to assess agreement between measured relative VO_2max during the walking test and that of the running test (Bland & Altman, 1986).

RESULTS

Descriptive statistics for the firefighters and performance indicators during the VO_2max test are shown in Table 1. All of the firefighters met the criteria for achieving VO_2max . Influential diagnostics revealed no outliers. Relative VO_2max was normally distributed although the average was slightly high (48.4 ± 6.5 ml/kg/min) indicating that the sample was relatively fit. The stepwise linear regression included time achieved on the test as the only significant variable predicting VO_2max ($p < 0.001$). Time explained 76% of the variation in VO_2max ($R^2 = .76$) while the SEE for the linear prediction was 3.2 ml/kg/min. The results of the regression are shown in Table 2. The equation derived is as follows:

$$\text{VO}_2\text{max (ml/kg/min)} = 11.373 + \text{time (minutes)} * 2.184$$

[Insert Table 1]

[Insert Table 2]

Figure 1 shows a plot of the actual VO_2max of the participants during the walking test and the predicted VO_2max derived from the equation.

Cross validation: On average, participants' measured relative VO_2max during the walking test was 4.62 ± 5.86 ml/kg/min lower than their VO_2max during the running test. The difference ranged from -11.1 to 9 ml/kg/min. The Bland-Altman plot in Figure 2 depicts the limits of agreement (2 standard deviations above and below the mean difference); the lower limit was -16.34 (95% CI -10.2 to -22.47) while the upper limit was 7.11 (95% CI 0.97 to 13.24).

[Insert Figure 1]

[Insert Figure 2]

DISCUSSION

We sought to develop a treadmill walking protocol and corresponding equation for predicting VO_2max in firefighters that would take minimal time and resources. The weighted vest protocol we developed resulted in all firefighters reaching their VO_2max . The protocol also has exceptional facility for predicting VO_2max . The prediction equation derived from our test has a smaller SEE (3.2 ml/kg/min) than the Gerkin protocol (3.7 ml/kg/min) (Tierney et al., 2010) and the Bruce protocol (3.35 ml/kg/min) which is the most widely used treadmill test in existence (Heyward, 1997).

The challenge however, when aiming to create a test that does not require an exercise testing treadmill, is that a standard treadmill is not capable of extremely high grade increases. This is why the Bruce or Balke protocol, for example, cannot be conducted on a standard treadmill. For the making of this (Moore) protocol, we were able to use an exercise testing

treadmill and as such, we were able to increase the grade to 19% for the longest test in our study (22 minutes). However, if this test were to be conducted in the field, some participants would reach the maximal grade on a standard treadmill before reaching exhaustion. Most standard, commercially available treadmills are capable of 15% grade. According to this protocol, a participant must achieve a time of 19 minutes in order to reach a 15% grade. The predicted VO_2max of a person achieving a time of 19 minutes on this test is 52.9 ml/kg/min. Recall the objective of this test is to screen firefighters for low aerobic capacity. A VO_2max of 52.9 ml/kg/min is very high for any adult and well above the identified risk threshold for firefighters of 42 ml/kg/min. In our relatively fit sample of firefighters, six of the thirty-eight participants walked for longer than 19 minutes. The mean VO_2max of these individuals was 57.9 ml/kg/min while all had measured VO_2max values well above 42 ml/kg/min. Thus, we believe this protocol to be a useful and valuable screening tool for the fire service, though we acknowledge it may not be suitable for predicting VO_2max of highly fit firefighters.

Cross-validation confirmed that it is possible for firefighters' VO_2max to be underestimated by this protocol although the two observations that yielded the greatest difference (-11 ml/kg/min) were associated with a walking time of ≥ 20 minutes, which as mentioned could not be accomplished on a standard treadmill. Further, the greatest differences between VO_2max values measured during running versus the walking test tended to be among those with higher fitness levels. It is well known that people's VO_2max can differ from one mode to another (bike vs. treadmill, for example) and this is primarily dependent on the individual's proficiency in the exercise mode being used to measure aerobic capacity (Nieman, 2006). While VO_2max was underestimated by more than 5 ml/kg/min for 7 of the 13 individuals in the cross-validation group (54%), three participants (23%) yielded the same or higher VO_2max during walking compared to running. It is possible that leg fatigue induced by wearing a weighted vest

contributed to the trend toward achieving a lower VO_2max during walking compared to running but we do not have data to investigate whether this is true. Further testing across a broader range of fitness levels is needed to better understand the true utility of the Moore protocol.

One outcome of the pre-testing, protocol development phase was the finding that an extended warm-up was necessary for this test. This adjustment was made after two of our initial participants complained of back pain and shin splints during the test. This led us to the hypothesis that walking with the weighted vest may place significant demands on the trunk and lower extremities (possibly greater than running). In response to these complaints, we implemented a 5-minute treadmill walk without the weighted vest followed by 5 minutes of targeted stretches to the back and hamstrings before beginning the test (which includes another warm-up of 3 minutes of walking at 3.0 mph at 0% grade). This protocol change was well received and resulted in no further complaints from the remainder of the study participants.

Due to the high rate of back injury among the firefighter population, we recommend that firefighters undergoing the test should be coached to avoid bending forward at their waist when fatigue begins to set in. At higher intensities we often had to encourage participants to “stand up straight” as a precaution to prevent increased spinal loads. Data support that spinal loads, and subsequently stress may increase with forward bending that promotes greater spinal flexion (McGill, 1997).

Aside from the low SEE, and the fact that this test is job specific, a strength of our protocol is that it will be very feasible for fire departments to implement. First, it requires little training to administer. The tester need only to weigh the participant, calculate 20% of their body weight and ensure the weighted vest carries that amount of weight (being careful to account for the weight of the vest alone). Second, since our test requires only a standard treadmill, a weighted vest and a qualified professional to administer it, the financial investment for a fire

department is likely meager. Moreover, if a cardiac event is avoided as a result of undergoing the test, the return on investment would be astronomical.

One limitation of our study is that the prediction equation developed is only applicable to male firefighters as we were only able to recruit two female firefighters; too few to include in our analysis. A second limitation is that we were not able to derive a submaximal test because the weighted vest tended to cause artifact with our 12-lead ECG so we felt the measurement of heart rate was not precise enough for those purposes. However, many authors have stated that it is preferable for firefighters to undergo maximal exercise testing as opposed to submaximal since the prediction of VO_2max is much more accurate using a maximal protocol (Tierney et al., 2010) and because it is important to screen firefighters for cardiac complications before they enter into physical situations on-duty that require near maximal exertion (Angerer, Kadlez-Gebhardt, Delius, Raluca, & Nowak, 2008; Raymond & Barringer, 2009). One of the major advantages of utilizing a VO_2max test is that it can also serve as a cardiac “stress test”. Though not necessary for the determination of VO_2max , a qualified exercise physiologist or other health professional can perform the test while the participant is connected to an ECG and interpret the data. Many exercise physiologists work with fire departments across the country and could use this (Moore) protocol to perform these dual services (measuring VO_2max and conducting a stress test). Firefighters who possess abnormalities on the ECG can then be encouraged to see their cardiologist. In the American Journal of Cardiology, physicians Raymond and Barringer claim that performing submaximal tests does not properly simulate the working conditions of firefighters and that relying on these tests for screening would result in failure to identify those at risk for experiencing myocardial ischemia (poor perfusion) or other life-threatening conditions during the high intensity activities that they constantly contend with as a function of their jobs (Raymond & Barringer, 2009).

Although there is a fairly large body of literature surrounding firefighter health, the incidence of heart attacks has remained devastatingly high over the past ten years (Kales et al., 2007; Soteriades et al., 2011). As such, there is clearly a need for adequate testing and screening for low aerobic capacity in this population. Currently in the arsenal of VO_2 max tests which can be used by fire departments are the FDNY stairclimb protocol and the Gerkin treadmill running protocol which both have adequate equations for predicting VO_2 max from a submaximal and a maximal effort (available in the 3rd edition of the “Fire Service Joint Labor Management Wellness-Fitness Initiative”). Yet, these tests may be insufficient for the following reasons: 1) stepping may not be representative of job demands for those outside of large cities (Tierney et al., 2010), 2) fire departments may be less likely to possess a stairclimber over a treadmill, and the Gerkin protocol is not feasible for firefighters who cannot run. This (Moore) protocol allows for excellent prediction of VO_2 max, utilizes the most typical piece of exercise equipment owned by most fire departments, is practical for all firefighters, and is more representative of the job demands of most firefighters than running or climbing steps.

Table 1

Descriptive Statistics and Performance Indicators on the Walking VO₂max Test (N=38)

Parameter	Mean	SD	Range
Age	31.2	7.7	20-44
Height (cm)	177.7	6.9	162-195
Weight (Kg)	87.4	17.4	67.5-165
Walking speed (mph)	4.0	0.1	3.6-4.3
VO ₂ max (ml/kg/min)	48.4	6.5	30-66.3
Time on test (minutes)	16.95	2.57	8-22
Maximal RER (during walking)	1.11	0.04	1-1.2

Table 2

Results of the Stepwise Linear Regression for the Walking VO₂max Test (N=38)

Parameter	coefficient	β	p
Time	2.184	0.87	<0.001
Intercept	11.373		

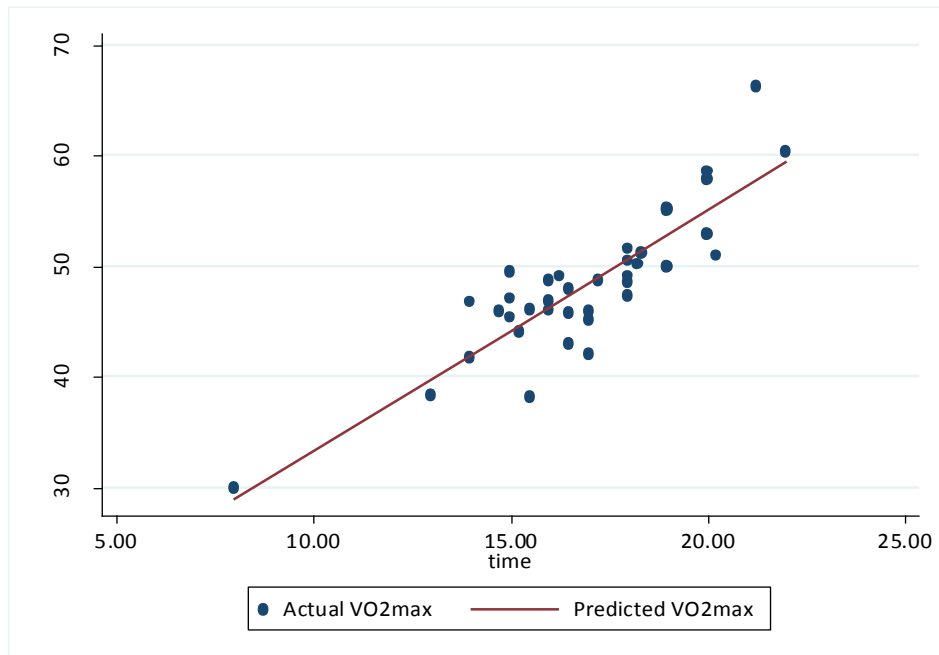


Figure 1: Actual versus predicted VO₂max for the Moore equation. VO₂max values of firefighters (N=38) during the walking test (circles) and the predicted VO₂max derived from the equation (line) are plotted above. The Standard Error the Estimate for the equation was 3.2 ml/kg/min.



Figure 2: Agreement between VO₂max during walking and running. The Bland-Altman plot above depicts the limits of agreement (2 standard deviations above and below the mean difference) between measured relative VO₂max during the walking test and VO₂max during a running test among firefighters (n=13). The mean difference (Walking VO₂max – Running VO₂max) was -4.62 ± 5.86 ml/kg/min. The lower limit of agreement was -16.34 (95% CI -10.2 to -22.47) while the upper limit was 7.11 (95% CI 0.97 to 13.24).

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CHAPTER FIVE

CONCLUSION

This dissertation highlights significant gaps in the literature related to fitness, performance and the incidence of back injuries and heart attacks in firefighters. While some research has illustrated that the physical demands of firefighting contribute to the high incidence of injury and death in this population, there are few if any screening protocols to aid in preventing these events.

The results of our first two studies confirm that firefighters experience an unusually high incidence of back injuries. However, we did not find that firefighters who scored well on a battery of back-fitness tests experienced fewer back injuries than less-fit firefighters in our study sample. We did find that increasing lumbar extension flexibility increased the risk of back injury. It is possible that excessive motion at the spine increases the risk for injury in response to the repetitive stresses from lifting and other spine-loading tasks common among firefighters. Certainly, more research must be conducted to better understand this finding.

We failed to ascertain a relationship between perception of fitness and injury history in our sample of firefighters. Our results indicate that perceived fitness does not affect injury risk or mediate the effect of fitness on back injury risk in firefighters. However, we hypothesize that perception of fitness may instead direct firefighters' behaviors when performing in a physically demanding setting, which may in turn affect injury risk. This hypothesis needs to be tested.

Lastly, we have demonstrated that firefighters' aerobic capacity can be safely measured by walking on a treadmill to exhaustion while wearing a weighted vest. The predicted VO_{2max} from this walking test was very accurate; within a standard error of the estimate of 3.2

ml/kg/min. These findings have led to the development of a new test to predict VO_2max in firefighters for the purpose of screening for low aerobic capacity; a previously identified risk factor for heart attack in this population. The new (Moore) protocol is suitable and feasible for use in the fire service since it only requires a standard treadmill and the test is likely more job-specific compared to other forms of testing such as running.

As a result of this research some conclusions can be drawn:

- 1) Scores on the Chin-up, Lumbar flexion, Hamstring Strength, Back Strength and Back Endurance tests that we employed are not related to history of back injury in firefighters.
- 2) Greater flexibility in lumbar extension is associated with a history of back injuries in firefighters. As such, it may be important to assess back extension flexibility and counsel firefighters about proper mechanics to lower their risk for back injury.
- 3) Scores on the Strength and Condition subscales of the Physical Self Perception Profile (PSPP) are not associated with firefighters' history of back injury.
- 4) Perception of fitness, as assessed by the Strength and Condition subscales of the PSPP, does not appear to mediate the relationships between actual fitness and back injuries in firefighters.
- 5) Firefighters in our sample appear to have an accurate sense of their strength as scores on the Strength subscale of the PSPP were significantly correlated with the back strength tests in our back fitness test battery (Back Strength and Hamstring Strength tests).
- 6) A job-specific treadmill walking protocol utilizing a weighted vest is a suitable test for predicting the VO_2max of structural firefighters within 3.2 ml $\text{O}_2/\text{kg}/\text{min}$.

- 7) For some firefighters, a maximal exercise test involving walking on a treadmill wearing a weighted vest may yield a lower $VO_2\text{max}$ compared to a test that requires running on a treadmill. However, this occurred predominately among the fittest firefighters in our sample. Thus while it may reduce the accuracy of predicting actual $VO_2\text{max}$ among fitter firefighters, it does not detrimentally affect the utility of the test for identifying those at the greatest risk.

This dissertation also suggests areas for further study:

- 1) The relationships between fitness, especially lumbar extension flexibility, and back injury risk in firefighters should be studied prospectively. Observing firefighters' back injuries over time and relating those to scores on a variety of fitness tests is the best strategy to confirm or deny the assumption that highly fit firefighters are at a reduced risk of sustaining back injuries.
- 2) To better understand how firefighters' perceptions of their fitness affects their injury risk researchers should investigate how those perceptions direct firefighters' choices when faced with risky lifting tasks; whether firefighters who believe themselves to be highly fit enter into more hazardous situations or perform tasks in an unsafe manner.
- 3) A prospective longitudinal study is necessary to confirm that regularly screening firefighters for $VO_2\text{max}$ using the Moore protocol is a viable strategy for reducing the incidence of heart attacks in this population.
- 4) The relationships between fitness and heart attack and back injury risk needs to be studied in female firefighters as the sample of firefighters in this dissertation included too few females to include in our analysis.

- 5) The Moore treadmill walking protocol that was developed from this dissertation needs to be further tested among female as well as older and less aerobically fit firefighters to improve upon the equation for predicting VO_2max .

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APPENDIX

CONSENT FORM 1

Project Title:	Investigating the relationships between perceived fitness, actual fitness and back injuries in firefighters
Principal Investigator:	Kathy Gunter, PhD
Student Researcher:	Karlie Friesen, MS
Co-Investigator(s):	Salvador Jaime, Luke Thomas
Sponsor:	None
Version Date:	4/1/2011

1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to investigate the relationships between perceived fitness, actual fitness and back injuries in firefighters. We are conducting this study to understand how firefighters perceive their own fitness level and how that relates to their performance on fitness tests and their history of back injury. We also want to discover which, if any, fitness parameters may be associated with prior history of back injury so that we can identify some risk factors for back injury and help firefighters lower their risk of experiencing one.

This study is being conducted by Karlie Friesen for the completion of her dissertation. Up to 300 firefighters may be invited to take part in this study.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a career firefighter.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

The study activities today involve completing a survey. There is a second part which involves participating in a short battery of fitness tests to assess trunk strength and flexibility. The fitness testing will take place at your station at a later date. You do not have to participate in both parts of the study; you may choose to only complete the survey, but you must complete the survey in order to participate in fitness testing. Anyone can participate in the portion of the study that involves filling out the survey. In order to also participate in the fitness testing component of the study, you must be free from injury that would hinder your performance on any fitness test involving your back, neck and legs.

The survey today will take about 15 -30 minutes to complete.

Because it is not possible for us to know what studies may be a part of our future work, we ask that you give permission now for us to use your personal information without

being contacted about each future study. Future use of your information will be limited to studies about firefighter health. If you agree now to future use of your personal information, but decide in the future that you would like to have your personal information removed from research database, please contact Kathy Gunter at Kathy.Gunter@oregonstate.edu or (541)737-1405.

_____ You may store my information for use in future studies.
Initials

_____ You may not store my information for use in future studies.
Initials

We may contact you in the future for another similar study. You may ask us to stop contacting you at any time.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

There is a risk that we could accidentally disclose information that identifies you. However, we have measures in place to avoid this such as keeping your information on a password protected computer, replacing your name with an ID number once your information is entered and storing paper documents in a locked file cabinet.

6. WHAT ARE THE BENEFITS OF THIS STUDY?

This study is not designed to benefit you directly.

7. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study.

10. DOES ANY MEMBER OF THE STUDY TEAM HAVE A CONFLICTING INTEREST?

Karlie Friesen, an investigator on this study, may have a potential conflict of interest as she is the owner of Fire Fitness Northwest, a company that provides fitness testing and wellness program services to fire departments.

If you have questions or concerns about this, please contact the Institutional Review Board Office at (541) 737-8008.

9. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

If the results of this project are published your identity will not be made public.

To help ensure confidentiality, the data from your survey responses are entered electronically into files stored on password protected computers accessible only by project personnel. All paper documents (data collection sheet, survey and Informed Consent documents) will be stored in a locking file cabinet in the principle investigators private office for 3 years. This office is always locked unless the Principle Investigator is in the office.

9. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports..

10. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact:

Kathy Gunter, PhD

Kathy.Gunter@oregonstate.edu

(541)737-1405

or

Karlie Friesen, MS

Friesenk@onid.orst.edu

(541)261-0849

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office at (541) 737-8008 or by email at IRB@oregonstate.edu.

12. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: Delete this line only if the study is exempt from full board review. The IRB will insert the appropriate date when the consent form is approved.

Participant's Name (printed):

(Signature of Participant)

(Date)

(Signature of Person Obtaining Consent)

(Date)

(Parent/Guardian/ Legally Authorized Representative)

(Date)

CONSENT FORM 2

Project Title:	Investigating the relationships between perceived fitness, actual fitness and back injuries in firefighters
Principal Investigator:	Kathy Gunter, PhD
Student Researcher:	Karlie Friesen, MS, Luke Thomas, Amy Arnold
Co-Investigator(s):	
Sponsor:	None
Version Date:	4/1/2011

1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to investigate the relationships between perceived fitness, actual fitness and back injuries in firefighters. We are conducting this study to understand how firefighters perceive their own fitness level and how that relates to their performance on fitness tests and their history of back injury. We also want to discover which, if any, fitness parameters may be associated with prior history of back injury so that we can identify some risk factors for back injury and help firefighters lower their risk of experiencing one.

This study is being conducted by Karlie Friesen for the completion of her dissertation. Up to 300 firefighters may be invited to take part in this study.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a career firefighter.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

There are two parts to this study: the first part involves completing a survey and the second part involves participating in a short battery of fitness tests to assess trunk strength and flexibility. The second part takes place today. You may have already received an email about this study and completed the first portion online. If you did not, you can still participate in either the first part of the study or both parts today.

In order to participate in the fitness testing today, you must have filled out the survey and you must be free from injury that would hinder your performance on any fitness test involving your back, neck and legs.

If you choose to participate in fitness testing today, you will come to the fitness room and hand this Informed Consent to Ms. Friesen. She will then ask you to choose a piece of cardio equipment to warm-up with (treadmill, bike, etc.). After warming up for 5 minutes, you will begin the fitness testing. We estimate the fitness testing will

take approximately 25 minutes for each firefighter; this includes the 5-minute warm-up period.

Fitness Testing

You will complete the following fitness tests, in this order, in a circuit. Barriers will be placed in the room to ensure privacy at each station.

1. Chin-up Test: you will begin lying face down on a mat, you will be instructed to slowly arch your back so your head and chest come off the ground
2. Trunk Rotation Test: you will sit in a chair with a Velcro strap wrapped around your chest. You will then be instructed to slowly rotate as far as possible to each side.
3. Lumbar Range of Motion Test: you will stand with your back to the researcher and pull the back of your shirt up to the level of the sternum. The researcher will feel for the protruding part of your hip bone on the back side, near the waist, and then make two marks on your skin. You will then be asked to bend all the way forward and backward at the waist. Whenever possible, Ms. Friesen will collect these data on female firefighters. Note: we will not be asking you to remove your shirt.
4. Hip Extensor Endurance (Knee Flexion) Test: You will sit on the edge of a bench or chair with one leg extended and a resistance band connected to your ankle with a Velcro strap. The researcher will hold the ends of the resistance band while you bend your knee to 90°, against the resistance from the band. You will perform as many repetitions as you can to a cadence of 80 beats per minute.
5. Upper Back Strength Test: you will stand on the dynamometer and pick up the handle. Before pulling on the handle you will be given instructions to ensure proper form. You will then be instructed to pull up on the handle and pinch your shoulder blades together in a maximal effort.
6. Upper Back Endurance Test: you will again stand bent over at the waist and with the knees bent to 45 degrees. This time, however, you will bend over slightly more than in the upper back strength test (approximately 75 degrees at the waist) while holding a 20 pound hand weight in each hand. You will be instructed to perform a “bent-over row” by pulling the hand weights up to your chest while gliding your elbows along your sides.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

The risks while completing these assessments of muscular fitness and flexibility include injury during a test and some latent muscle soreness. If soreness does occur, it will likely last between 1 and 3 days. The possibility of a you being injured during one of these tests is minimal and would only result from extreme overexertion. The risk of soreness or injury is reduced by having you warm-up for 5 minutes before testing and by having you undergo the least strenuous tests first and the more strenuous tests at the end of the circuit.

There is also potential for discomfort or embarrassment while completing the fitness tasks in the same room with other participants. We will attempt to minimize this by keeping everybody moving continuously through the circuit of exercises and arranging the stations so that you are facing a wall while performing a test and not the center of the room or another participant.

6. WHAT HAPPENS IF I AM INJURED?

Oregon State University has no program to pay for research-related injuries. If you think that you have been injured as a result of being in this study, you should follow your fire department's procedures for reporting and receiving medical care for an injury while on-duty.

7. WHAT ARE THE BENEFITS OF THIS STUDY?

This study is not designed to benefit you directly.

8. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study.

9. DOES ANY MEMBER OF THE STUDY TEAM HAVE A CONFLICTING INTEREST?

A conflict of interest occurs when a researcher or the University has a financial or other business interest that could affect the research. In some situations, the results of a study might lead to a financial gain for the investigator(s) and/or the University.

One or more of the investigators working on this study has a potential conflict of interest. Karlie Friesen, an investigator on this study, is the owner of Fire Fitness Northwest, a company that provides fitness testing and wellness program services to fire departments. She is currently contracted with the Corvallis Fire Department to provide their Wellness program.

If you have questions or concerns about this, please contact the Institutional Review Board Office at (541) 737-8008.

10. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

If the results of this project are published your identity will not be made public.

To help ensure confidentiality, the data from your survey responses are entered electronically into files stored on password protected computers accessible only by project personnel. All paper documents (data collection sheet, survey and Informed

Consent documents) will be stored in a locking file cabinet in the principle investigators private office for 3 years. This office is always locked unless the Principle Investigator is in the office.

11. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. Your decision of whether to participate in this study will in no way impact your employment. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports..

12. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact:

Kathy Gunter

Kathy.Gunter@oregonstate.edu

(541)737-1405

or

Karlie Friesen

Friesenk@onid.orst.edu

(541)261-0849

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

13. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: Delete this line only if the study is exempt from full board review. The IRB will insert the appropriate date when the consent form is approved.

Participant's Name (printed):

(Signature of Participant)

(Date)

(Signature of Person Obtaining Consent)

(Date)

(Parent/Guardian/ Legally Authorized Representative)

(Date)

	Really True For Me	Sort of True For Me				Sort of True For Me	Really True For Me
3.	[]	[]	Some firefighters make certain that they take part in some form of regular vigorous physical exercise	BUT	Others don't often manage to keep up regular vigorous physical exercise.	[]	[]
4.	[]	[]	Some firefighters feel that their muscles are much stronger than most others of their sex	BUT	Others feel that on the whole their muscles are not quite so strong as most others of their sex	[]	[]
5.	[]	[]	Some firefighters do not usually have a high level of stamina and fitness	BUT	Others always maintain a high level of stamina and fitness.	[]	[]
6.	[]	[]	When it comes to situations requiring strength, some firefighters are one of the first to step forward	BUT	When it comes to situations requiring strength, some firefighters are one of the last to step forward.	[]	[]
7.	[]	[]	Some firefighters tend to feel a little uneasy in fitness and exercise settings	BUT	Others feel confident and at ease at all time in fitness and exercise settings.	[]	[]
8.	[]	[]	Some firefighters tend to lack confidence when it comes to their physical strength	BUT	Others are extremely confident when it comes to their physical strength.	[]	[]
9.	[]	[]	Some firefighters feel extremely confident about their ability to maintain regular exercise and physical conditioning	BUT	Others don't feel quite so confident about their ability to maintain regular exercise and physical conditioning.	[]	[]
10.	[]	[]	Some firefighters feel that they are very strong and have well developed muscles compared to most people	BUT	Others feel that they are not so strong and their muscles are not very well developed.	[]	[]

	Really True For Me	Sort of True For Me			Sort of True For Me	Really True For Me
11.	[]	[]	Some firefighters feel that compared to most they always maintain a high level of physical conditioning	BUT	Others feel that compared to most their level of physical conditioning is not usually so high.	[] []
12.	[]	[]	Some firefighters feel that they are not as good as most at dealing with situations requiring physical strength	BUT	Others feel that they are among the best at dealing with situations which require physical strength.	[] []

SURVEY PART 2: BACKGROUND AND HISTORY OF BACK INJURY

- Name: _____
Last First age gender
- How many years have you been a career (paid) firefighter? _____
- Are you currently suffering from any injuries or pain in your back, neck or legs right now?
 - Yes
 - No

If you answered Yes but would like to clarify, or if you are unsure how to answer, please provide more information here:
- Assume that a “back injury” describes something that happened **at work only** that resulted in moderate to severe pain in your back for a prolonged period of time. These may or may not be injuries that caused you to miss work days. In that sense, have you ever experienced a back injury while on duty as a firefighter?
 - Yes
 - No

If you answered No to this question, you are done with the survey!

5. How many back injuries have you experienced throughout your career?
 - a. 1
 - b. 2
 - c. 3 or more
6. Have you ever had a back injury/or injuries that caused you to miss work?
 - a. Yes
 - b. No
7. If you answered yes to the last question, approximately how many weeks have you been off work due to a back injury or injuries (total from all injuries)? _____
8. How long ago was your last back injury? _____
9. In order to find out as much about the injury/injuries as possible, I am going to ask you to describe it/them in several ways. First, what actions do you believe caused your injury/injuries? Circle ALL that apply.
 - a. Lifting
 - b. Twisting (this can be twisting WHILE lifting if you feel that the combination of the two caused the injury. If so, circle answers a *and* b)
 - c. Bending over (this can be bending over WHILE lifting if you feel that the combination of the two caused the injury. If so, circle answers a *and* c)
 - d. A slip or trip that led to a landing either on the ground or on an object/obstacle lower than standing height.
 - e. Compression/jarring force (such as a hard landing on a seat while sitting)

f. Other. Please describe _____

10. What is the best way to describe the type of injury/injuries you have experienced? circle

ALL that apply

- a. Strained muscle/ligament in back
- b. Vertebral fracture
- c. Slipped disc/herniated disc
- d. General pain – exact type of injury unknown
- e. Other

11. What areas of the back have you injured? Circle ALL that apply

- a. Upper back
- b. Lower back
- c. Indicate the exact location if you know it (ie: L4-L5)

CONSENT FORM 1

Project Title:	Development of a treadmill walking test to predict VO ₂ max in firefighters
Principal Investigator:	Kathy Gunter, PhD
Student Researcher:	Karlie Moore, MS
Co-Investigator(s):	none
Sponsor:	none
Version Date:	1/30/2012

1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to develop a treadmill walking test to predict VO₂max in firefighters. We are interested in developing a test that can be conducted in a fire station and requires only walking which will allow firefighters to learn what their aerobic capacity is. This study is being conducted by Karlie Moore for the completion of her dissertation. Up to 500 firefighters may be invited to take part in this study.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a career firefighter on active duty.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

This study has two parts. However, not everybody will participate in the second part. In the first part, you will participate in a walking treadmill test to exhaustion (VO₂max test) while wearing a weighted vest. Some participants will be randomly selected to participate in the second part which is a running treadmill VO₂max test (without wearing the weighted vest). You will be notified within 4 weeks if you have been selected for the second part. You do not have to participate in the second part if invited and you can still participate in the walking treadmill test even if you already know that you do not want to participate in the running treadmill test. If you do participate in the running treadmill VO₂max test you will be given another Consent Form like this one.

Before participating in the fitness testing you should have refrained from ingesting alcohol or tobacco within 3 hours of your VO₂max test, you should be rested for your assessment and you should avoid significant exertion or exercise on the day of your VO₂max test. Although it is generally recommended that people refrain from ingesting food or caffeine within 3 hours of VO₂max testing, people differ in how they feel and perform with or without ingesting caffeine or food before strenuous exertion so use your best judgment and do what you know to be best for you.

In order to participate in the walking treadmill test you will first complete a Health History Questionnaire and have your height and weight measured. The researcher will assess your resting blood pressure and resting heart rate and will administer a resting electrocardiogram. If no contraindications to exercising are present, you will be asked to warm up on the treadmill by walking at a comfortable pace for 3 minutes. After the warm-up, you will be asked to step off the treadmill to put on a weighted vest. At that time you will also secure a mask around your mouth which you will breathe into throughout your entire test that measures your inspired oxygen and expired carbon dioxide. You will then be asked to step back onto the treadmill and bring the speed up to the fastest speed at which you can still walk. Throughout your test the researcher will take your blood pressure, monitor your heart rate and rhythm and will increase the incline on the treadmill. The test will be terminated when the researcher has established that you have reached your VO_2max based on specific criteria unless you request to stop before that point. You may request to discontinue your test at any time for any reason, without penalty. After your test is completed you will complete a 5 minute cool down by walking on the treadmill at a comfortable pace without wearing the weighted vest. At that time the researcher will tell you what your VO_2max is.

Also, one of your responsibilities as a study participant is to remain at the Human Performance Lab (HPL) while one other participant performs his treadmill test so that you may assist the researcher if an emergency event occurs during his test. Thus, you will be scheduled in pairs to ensure that extra medical aid is available during each person's test.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

The risks of participating in a VO_2max test may be fatigue, dizziness, nausea, chest pain and experiencing a cardiac event. According to the American College of Sports Medicine the overall risk of experiencing a cardiac event including heart attack, cardiac arrhythmia or sudden cardiac death is approximately 6 per 10,000 tests. In individuals without coronary artery disease, the risk of death during maximal exercise is estimated to be 1 per 15,000 to 18,000 people.

Several precautions will be taken to minimize the likelihood that you experience an adverse event during your treadmill test. Before your test, we will measure your resting heart rate and resting blood pressure and administer a resting ECG to ensure that you do not elicit any contraindications for participating in a maximal exercise test. Throughout your test, we will monitor your heart rhythm along with your heart rate, blood pressure and rate of perceived exertion to ensure that you are eliciting normal responses to exercise. The test will be terminated if you elicit any indications for terminating an exercise test. Before your test, you will undergo a 3 minute warm-up of walking at a comfortable speed on the treadmill in order to improve your cardiac response to strenuous exercise and increase blood flow to your muscle. Also, you will undergo a 5 minute cool down on the treadmill after your test is terminated to ensure that you will not experience a dramatic drop in blood pressure. Finally, you will be scheduled in pairs to ensure that extra medical aid is available in the case of an emergency. As stated in section 4, one of your responsibilities as a study participant is to assist the researcher if an

emergency event occurs while the other participant is undergoing his treadmill test. You will be asked to remain just outside the door of the Human Performance Lab when the other participant is taking his test to ensure that you may be called upon if needed.

6. WHAT HAPPENS IF I AM INJURED?

Oregon State University has no program to pay for research-related injuries. If you think that you have been injured as a result of being in this study, you should see your physician.

7. WHAT ARE THE BENEFITS OF THIS STUDY?

We do not know if you will benefit from being in this study. However, you will learn what your VO_2max is.

8. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study.

9. DOES ANY MEMBER OF THE STUDY TEAM HAVE A CONFLICTING INTEREST?

A conflict of interest occurs when a researcher or the University has a financial or other business interest that could affect the research. In some situations, the results of a study might lead to a financial gain for the investigator(s) and/or the University.

One or more of the investigators working on this study has a potential conflict of interest. Karlie Moore, an investigator on this study, is currently contracted with the Corvallis and Albany Fire Departments to provide their Wellness programs. The results of this study may be used by Karlie and other exercise physiologists who provide fitness assessments to firefighters to provide the best estimation of aerobic capacity for all firefighters. Karlie may use the results of this study to change her current practice but this is unlikely to affect her current contracts or benefit her financially. You should know that even if Karlie also provides your fitness assessment at work, your participation in this study does not fulfill any fitness testing requirements you may have as a part of your employment.

If you have questions or concerns about this, please contact the Institutional Review Board Office at (541) 737-8008.

10. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

If the results of this project are published your identity will not be made public. The results of this study will not be shared with your employer.

To help ensure confidentiality, the data from your VO₂max test is entered electronically into files stored on password protected computers accessible only by project personnel. All paper documents (Health History Questionnaire, Informed Consent documents) will be stored in a locking file cabinet in the principle investigators private office for 3 years. This office is always locked unless the Principle Investigator is in the office.

11. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. Your decision of whether to participate in this study will in no way impact your employment and regardless of your participation, you will still undergo any routine evaluations as required by your employer. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

12. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact:

Kathy Gunter

Kathy.Gunter@oregonstate.edu

(541)737-1405

or

Karlie Moore

Friesenk@onid.orst.edu

(541)261-0849

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

12. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: Delete this line only if the study is exempt from full board review. The IRB will insert the appropriate date when the consent form is approved.

Participant's Name (printed):

(Signature of Participant)

(Date)

(Signature of Person Obtaining Consent)

(Date)

CONSENT FORM 2

Project Title:	Development of a treadmill walking test to predict VO ₂ max in firefighters
Principal Investigator:	Kathy Gunter, PhD
Student Researcher:	Karlie Moore, MS
Co-Investigator(s):	none
Sponsor:	none
Version Date:	1/30/2012

1. WHAT IS THE PURPOSE OF THIS FORM?

This form contains information you will need to help you decide whether to be in this study or not. Please read the form carefully and ask the study team member(s) questions about anything that is not clear.

2. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to develop a treadmill walking test to predict VO₂max in firefighters. We are interested in developing a test that can be conducted in a fire station and requires only walking which will allow firefighters to learn what their aerobic capacity is. This study is being conducted by Karlie Moore for the completion of her dissertation. Up to 500 firefighters may be invited to take part in this study.

3. WHY AM I BEING INVITED TO TAKE PART IN THIS STUDY?

You are being invited to take part in this study because you are a career firefighter on active duty.

4. WHAT WILL HAPPEN IF I TAKE PART IN THIS RESEARCH STUDY?

This study has two parts. This is the second part, which is a running treadmill test to exhaustion (VO₂max test). You are being asked to participate in this second part because you participated in the first part, a walking treadmill VO₂max test while wearing a weighted vest, and you were randomly selected to be invited to participate in the running VO₂max test. You should not feel as if you have to participate today just because you participated in the walking treadmill test.

Before participating in the fitness testing you should have refrained from ingesting alcohol or tobacco within 3 hours of your VO₂max test, you should be rested for your assessment and you should avoid significant exertion or exercise on the day of your VO₂max test. Although it is generally recommended that people refrain from ingesting food or caffeine within 3 hours of VO₂max testing, people differ in how they feel and perform with or without ingesting caffeine or food before strenuous exertion so use your best judgment and do what you know to be best for you.

In order to participate in the running VO₂max test the researcher will go over with you your responses to the Health History Questionnaire (HHQ) that you completed for your walking VO₂max test and verify that your responses are still accurate. If any of your

responses have changed, you will be asked to complete a second HHQ. This running VO₂max test will be similar to your walking VO₂max test except that you will not be wearing a weighted vest and the treadmill speed, along with the incline, will gradually increase until you reach your VO₂max. Before your test the researcher will assess your resting blood pressure and resting heart rate and will administer a resting electrocardiogram (ECG). If no contraindications to exercising are present, you will be asked to secure a mask around your mouth which you will breathe into throughout your entire test that measures your inspired oxygen and expired carbon dioxide. You will then warm up on the treadmill by walking at a comfortable pace for 3 minutes. After the warm-up, the researcher will begin gradually increasing the speed as well as the incline on the treadmill. Throughout your test the researcher will take your blood pressure and monitor your heart rate and rhythm. The test will be terminated when the researcher has established that you have reached your VO₂max based on specific criteria unless you request to stop before that point. You may request to discontinue your test at any time for any reason, without penalty. After your test is completed you will complete a 5 minute cool down by walking on the treadmill at a comfortable pace. At that time the researcher will tell you what your VO₂max is.

Also, one of your responsibilities as a study participant is to remain at the Human Performance Lab while one other participant performs his treadmill test so that you may assist the researcher if an emergency event occurs during his test. Thus, you will be scheduled in pairs to ensure that extra medical aid is available during each person's test.

5. WHAT ARE THE RISKS AND POSSIBLE DISCOMFORTS OF THIS STUDY?

The risks of participating in a VO₂max test may be fatigue, dizziness, nausea, chest pain and experiencing a cardiac event. According to the American College of Sports Medicine the overall risk of experiencing a cardiac event including heart attack, cardiac arrhythmia or sudden cardiac death is approximately 6 per 10,000 tests. In individuals without coronary artery disease, the risk of death during maximal exercise is estimated to be 1 per 15,000 to 18,000 people.

Several precautions will be taken to minimize the likelihood that you experience an adverse event during your treadmill test. Before your test, we will measure your resting heart rate and resting blood pressure and administer a resting ECG to ensure that you do not elicit any contraindications for participating in a maximal exercise test. Throughout your test, we will monitor your heart rhythm along with your heart rate, blood pressure and rate of perceived exertion to ensure that you are eliciting normal responses to exercise. The test will be terminated if you elicit any indications for terminating an exercise test. Before your test, you will undergo a 3 minute warm-up of walking at a comfortable speed on the treadmill in order to improve your cardiac response to strenuous exercise and increase blood flow to your muscle. Also, you will undergo a 5 minute cool down on the treadmill after your test is terminated to ensure that you will not experience a dramatic drop in blood pressure. Finally, you will be scheduled in pairs to ensure that extra medical aid is available in the case of an emergency. As stated in section 4, one of your responsibilities as a study participant is to assist the researcher if an emergency event occurs while the other participant is undergoing his treadmill test. You

will be asked to remain just outside the door of the Human Performance Lab when the other participant is taking his test to ensure that you may be called upon if needed.

6. WHAT HAPPENS IF I AM INJURED?

Oregon State University has no program to pay for research-related injuries. If you think that you have been injured as a result of being in this study, you should see your physician.

7. WHAT ARE THE BENEFITS OF THIS STUDY?

We do not know if you will benefit from being in this study. However, you will learn what your VO_2max is.

8. WILL I BE PAID FOR BEING IN THIS STUDY?

You will not be paid for being in this research study.

9. DOES ANY MEMBER OF THE STUDY TEAM HAVE A CONFLICTING INTEREST?

A conflict of interest occurs when a researcher or the University has a financial or other business interest that could affect the research. In some situations, the results of a study might lead to a financial gain for the investigator(s) and/or the University.

One or more of the investigators working on this study has a potential conflict of interest. Karlie Moore, an investigator on this study, is currently contracted with the Corvallis and Albany Fire Departments to provide their Wellness programs. The results of this study may be used by Karlie and other exercise physiologists who provide fitness assessments to firefighters to provide the best estimation of aerobic capacity for all firefighters. Karlie may use the results of this study to change her current practice but this is unlikely to affect her current contracts or benefit her financially. You should know that even if Karlie also provides your fitness assessment at work, your participation in this study does not fulfill any fitness testing requirements you may have as a part of your employment.

If you have questions or concerns about this, please contact the Institutional Review Board Office at (541) 737-8008.

10. WHO WILL SEE THE INFORMATION I GIVE?

The information you provide during this research study will be kept confidential to the extent permitted by law. Research records will be stored securely and only researchers will have access to the records. Federal regulatory agencies and the Oregon State University Institutional Review Board (a committee that reviews and approves research studies) may inspect and copy records pertaining to this research. Some of these records could contain information that personally identifies you.

If the results of this project are published your identity will not be made public. The results of this study will not be shared with your employer.

To help ensure confidentiality, the data from your VO₂max test is entered electronically into files stored on password protected computers accessible only by project personnel. All paper documents (Health History Questionnaire, Informed Consent documents) will be stored in a locking file cabinet in the principle investigators private office for 3 years. This office is always locked unless the Principle Investigator is in the office.

11. WHAT OTHER CHOICES DO I HAVE IF I DO NOT TAKE PART IN THIS STUDY?

Participation in this study is voluntary. Your decision of whether to participate in this study will in no way impact your employment and regardless of your participation, you will still undergo any routine evaluations as required by your employer. If you decide to participate, you are free to withdraw at any time without penalty. You will not be treated differently if you decide to stop taking part in the study. If you choose to withdraw from this project before it ends, the researchers may keep information collected about you and this information may be included in study reports.

12. WHO DO I CONTACT IF I HAVE QUESTIONS?

If you have any questions about this research project, please contact:

Kathy Gunter

Kathy.Gunter@oregonstate.edu

(541)737-1405

or

Karlie Moore

Friesenk@onid.orst.edu

(541)261-0849

If you have questions about your rights or welfare as a participant, please contact the Oregon State University Institutional Review Board (IRB) Office, at (541) 737-8008 or by email at IRB@oregonstate.edu

12. WHAT DOES MY SIGNATURE ON THIS CONSENT FORM MEAN?

Your signature indicates that this study has been explained to you, that your questions have been answered, and that you agree to take part in this study. You will receive a copy of this form.

Do not sign after the expiration date: Delete this line only if the study is exempt from full board review. The IRB will insert the appropriate date when the consent form is approved.

Participant's Name (printed):

(Signature of Participant)

(Date)

(Signature of Person Obtaining Consent)

(Date)

Do you have any other chronic illnesses that you have not informed the researcher of thus far? If yes, please explain_____

Have you ever had an abnormal stress test or an abnormal resting or exercise ECG? If yes, please explain_____

Did a doctor review it?_____Did the doctor state that was normal for you?_____

Orthopedic concerns:

List any past injuries that may be of concern during your test VO2max test:

List any current injuries or aches and pains that may be of concern/limit your abilities during your VO2max test:

Before proceeding with this study, please initial that you know the information you provided on this Questionnaire to be true and accurate. _____

